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Hughes,
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CHANNEL EROSION RISK INDEX

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CHANNEL EROSION RISK INDEX

by
William C. Hughes
Civil and Urban Engineering
University of Colorado - Denver
1100 14th Street
Denver, Colorado 80202
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CHANNEL EROSION RISK INDEX

I. INTRODUCTION

High density resort development and roadway construction inevitably produce greater volumes of flow and higher flood discharges in adjacent streams, leading to channel erosion and a deterioration of the physical water quality. In dealing with the possibility of erosion brought on by these changes, planners and designers are often faced with the problem of appraising whether the potential for erosion is sufficient to justify either erosion protection measures or a more extensive erosion study, usually with only a minimum amount of information.

This report describes a procedure to aid planners and designers in making such an appraisal. First, by providing field-derived data relating the probability of significant erosion (erosion potential) in a natural channel to flow rate, hydraulic characteristics and soil classification; and second, a technique for combining the erosion potential and the frequency of the design flow into a single index (erosion risk index). The erosion risk index is expressed in terms of the probability of significant erosion in any given year, or in terms of a recurrence interval, which provides planners and designers with a method to quickly access the likelihood that development along or near a stream channel might significantly increase channel erosion.

II. BACKGROUND

Estimating whether an anticipated channel modification will result in downstream erosion is very often less exact and more difficult than the selection and design of an appropriate erosion control measure. Theoretical attempts to model erosion in terms of particle motion, from the pioneering work of Einstein (1) to more recent work by Gessler (3) and Todorovic and Nordin (11), are either still in the research stage or require a computational complexity and data which are too extensive for many planning and design problems. Empirically derived sediment yield equations, such as the Universal Soil Loss Equation (12) or the more recent model proposed by Smith, Fogel and Duckstein (10), suffer similar shortcomings.

Probably one of the most widely used approaches for the design of erodable channels involves the use of so-called permissible velocities, which were introduced early in this century by Fortier and Scobey (2). Essentially, permissible velocities are empirically derived upper limiting velocities which will assure a non-eroding channel for given general soil conditions and depths of flow. Since permissible velocities must assure a non-eroding channel they are inherently conservative and cannot adequately answer the questions to which this report addresses itself. More recent work by Keeley (5), although somewhat similar, provides information which is more useful for predicting the consequences of an anticipated channel modification. Keeley prepared scatter diagrams for various soil groups using either discharge and channel bed slope

or normal velocity and normal depth as variables (see Appendix C). Numerous field observations for a given soil classification were plotted on a diagram with bed slope (or velocity) as the ordinate and discharge (or depth) as the abscissa. If the observed channel was scoured, an estimated value of the associated peak discharge (depth) was plotted versus the bed slope (velocity) as a square and if no scour was apparent similar information was plotted as a circle. A line was then drawn on the diagram which separated the squares from the circles. The region above the line represented discharge and slope (depth and velocity) conditions conducive to channel erosion; and the region below the line represented conditions which did not produce channel erosion. Inspection of Keeley's relationships indicates that the data cannot be divided by a single line but that a band which contains both squares and circles is suggested. That is, rather than two regions, there are three. The upper region where erosion is assured, the lower region where channel stability is assured, and an intermediate region representing slope and discharge (depth and velocity) conditions which may or may not result in channel erosion. The upper boundary of the intermediate region can be thought of as representing the condition where the probability that erosion will occur is equal to one (erosion assured) and, similarly, the lower boundary represents a probability of erosion equal to zero, or no erosion.

The first phase of the study described in this report was an extension of Keeley's work which involved a field survey to obtain additional data points so that the aforementioned boundaries could

be more precisely established. The second phase involved assigning probabilities to the family of curves within the intermediate region, representing physical conditions for which the probability that erosion will occur is greater than zero but less than one. The latter have been designated erosion potential curves for the purposes of this report. In addition, the second phase of the study involved the development of a procedure to combine the erosion potential (probability of erosion given a particular discharge), with the probability of occurrence of the associated discharge, using established laws of probability and a standard flood frequency curve. The resulting joint probability, designated the erosion risk index in this report, provides a technique for accounting for situations where the likelihood of erosion is quite low - even in highly erodable channels - simply because erosion producing discharges occur so infrequently.

III. OBJECTIVES

The objectives of the research described herein were twofold. First, to establish sets of field-derived erosion potential curves, which relate the probability of significant channel erosion to channel discharge, (depth) and channel slope (velocity) for the following channel soil conditions: clay, silty-clay, sandy-silt, and gravel-silt. Second, to demonstrate a method for combining the aforementioned scour potential curves with the flood frequency curve for a given reach of stream channel to establish the erosion risk index for that reach of channel.

IV. METHOD

As previously mentioned the erosion potential curves are an extension of the work done by Keeley and the first phase of the study described in this report involved adding data points to Keeley's scatter diagrams.

A) Data Collection - Over 200 stream channels in New Mexico and Colorado were investigated and the following information gathered at each site: channel dimensions, channel bed slope, soil classification for material in channel bed and banks, an estimate of the most recent flood discharge and observation of the channel condition with respect to erosion. With the exception of a few sites, for which laboratory samples were obtained, soil classifications were based on field observations. Distinction between silt-clay and clay (low or high PI) was made from the texture of the sample when wet, and whether the wet sample could be rolled into a fine thread without crumbling. The determination of the discharge which produced the erosion state of a given channel was usually based on old high water marks, since most of the channels investigated were ungaged. In most cases channel reaches were chosen within a few hundred feet of culverts and the discharge estimated using culvert hydraulics and the high water marks upstream from the culvert. In some cases, the slope-area method was used in conjunction with high water marks. Where culverts were involved, attempts were made to investigate the channel far enough upstream (or downstream) from the culvert to nullify the effect of the culvert itself on the channel condition.

Since the objective was to relate the channel condition with the discharge which caused that condition, only recent evidence of erosion was considered. Erosion conditions were noted as stable, minor or beginning erosion and severe erosion. In selecting channel sites, attempts were made to choose sites which were free of large rocks and excessive vegetation in the channel.

In addition to the data from the field investigation, data was obtained from a literature search. In most cases usable data from the literature was the result of laboratory investigations and model studies of erosion.

B) Scatter Diagrams - The data was plotted on Keeley's scatter diagrams, using both sets of variables: discharge versus bed slope and velocity versus depth. With the latter, Keeley's procedure of computing normal depth and normal velocity from discharge, slope and channel cross-section was used. Because of missing bits of data and particular channel situations, some data was not considered acceptable for the normal depth-normal velocity computations which resulted in fewer data points with these variables. Also following Keeley's procedure, severe scour conditions were plotted with squares and stable channels with circles. Channels with minor or beginning erosion were plotted as triangles, but in most cases were treated as circles (no erosion) in the analysis. Two scatter diagrams - discharge versus slope and velocity versus depth were plotted for each of the following soil groups: sand-silt, silt-clay, clay and gravel-silt. The last soil group was not considered by Keeley, however, since so many of the channels investigated were in this soil group it was included.

The scatter diagrams were divided into three regions -- an upper region in which all the points were squares and a lower region in which all the points were circles, with a third region being the remaining intermediate band made up of circles and squares, which represents the region where erosion is probable but not assured. The term intermediate band as defined above will be used repeatedly throughout this report since this is the region of major interest. The upper boundary of the intermediate region represents an erosion potential approaching one (probability of erosion $\longrightarrow$ 1) and the lower boundary represents an erosion potential approaching zero (probability of erosion $\longrightarrow$ 0). Intervening erosion potentials form a family of curves within the intermediate band representing erosion probabilities between zero and one.

Equations were developed for the boundaries of the intermediate band on each diagram. The resulting equations were of the form:

$$\frac{(\text{slope})}{[\log\ (\text{Discharge})]^{-M}} = K_i \quad \ldots\ldots\ldots\ldots \quad (1)$$

or

$$\frac{(\text{velocity})}{(\text{depth})^{N}} = K_j \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where K_i and K_j are numerical representations of the erosion potential curves hereinafter referred to as curve numbers. Larger values of either K_i or K_j tended to be associated with severe erosion and the smaller values with stable channels. Curve numbers are parameters which combine the physical variables on the scatter diagram, so that each data point on the scatter diagram can be represented by a single unique value. In addition, since equation

one and equation two represent curves on their appropriate scatter diagrams, each unique value if K_i or K_j, also represents a unique erosion potential. The significance of the curve numbers is that they provide a parameter which is suitable for a frequency analysis and which also represent erosion potential curves on the scatter diagrams, thus providing the necessary tool for establishing the desired family of erosion probability curves within the intermediate band.

C) Frequency Analysis

The objective of this portion of the study was to establish a relationship between curve numbers (parameters combining physical variables related to erosion) and erosion potential (the probability of channel erosion). More precisely, we are seeking a means for computing the probability that channel erosion will occur, given that the reach of channel is represented by a unique curve number. If the symbol E denotes erosion and K signifies curve number, the above statement can be concisely represented by $P\{E|K = K'\}$, which will be used in the remainder of this report. There are several reasons why this relationship cannot be derived directly, but the most compelling is that since curve numbers can take on an infinite number of values, rarely will there be more than one or two with exactly the same magnitude, even in a large population of curve numbers. Thus there will always be an insufficient number of curve numbers direct probability computations. This situation can be improved by lumping together curve numbers with approximately the same magnitudes. Computationally this yields the probability

that erosion will occur when the given curve number is within an interval, or range, of values. Again this can be concisely stated as: $P\{E|K_a < K \leq K_b\}$. This statement is approximately equal to $P\{E|K = K'\}$ where $K' = \frac{1}{2}(K_a + K_b)$.

Within a chosen curve number interval, K_a to K_b, there will be a collection of observations, where each observation can have only one of two possible outcomes: observations where erosion occured represented by E, and observations where no erosion occured represented by NE. This situation is best represented by a binomial distribution where the probability of a successful event is related to the relative proportion of successes to the total number of trials.

$$P\{E|K_a < K \leq K_b\} = \frac{E}{E+NE} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Equation three is an approximation which improves as E + NE gets larger, becoming exact when E + NE approaches infinity. E + NE can be increased to improve the approximation by increasing the size of the interval K_a to K_b, however this involves a trade off since a wider interval yields less precision with respect to the location of K' on the scatter diagram. Figure 1 shows the relationship between curve numbers and erosion potential for sand-silt soils, where the erosion potentials were computed using equation three. The width of the curve number interval is shown by the horizontal width of the bar. The length of the vertical bar represents the 95% confidence interval which is a relative measure of how well equation three estimates the true probability of erosion, assuming

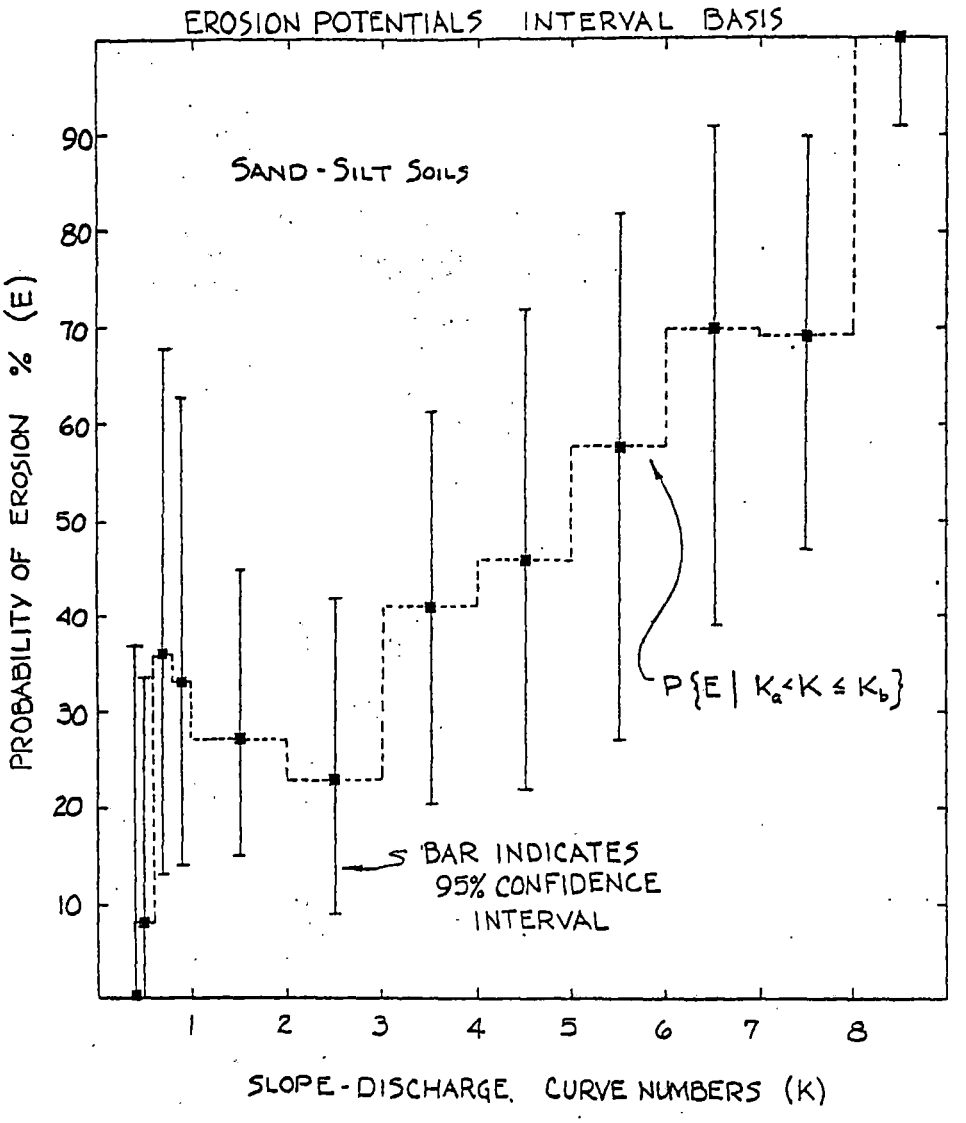

EROSION POTENTIALS INTERVAL BASIS
SAND - SILT SOILS
PROBABILITY OF EROSION % (E)
90
80
70
60
50
40
30
20
10
P{E | Ka<K ≤ Kb}
BAR INDICATES 95% CONFIDENCE INTERVAL
1
2
3
4
5
6
7
8
SLOPE - DISCHARGE CURVE NUMBERS (K)

Figure 1

a binomial distribution. As can be seen from Figure 1 the limited number of observations within each interval resulted in a rather wide confidence band. Although the confidence band could be reduced by increasing the curve number interval, any improvement would be offset by the loss of precision in plotting position on the scatter diagram.

One way to make better use of limited data is to accumulate the erosion observations (E) as well as the number of observations (E + NE) so that all the available data up to the given curve number are being used. This yields the probability that erosion will occur if the given curve number is less than or equal to a stated limit, and can be written:

$$P\{E|K \leq K_j\} = \frac{\Sigma E}{\Sigma E + NE}, \quad (\Sigma \text{ from } K = 0 \text{ to } K_j) \quad \ldots\ldots\ldots \quad (4)$$

Similarly, the probability that erosion will occur if the given curve number is greater than or equal to a stated limit is given by:

$$P\{E|K \geq K_i\} = \frac{\Sigma E}{\Sigma E + NE}, \quad (\Sigma \text{ from } K_i \text{ to } K = K_{max}) \quad \ldots\ldots\ldots \quad (5)$$

In equation 4 the curve number interval extends from a curve number of zero to the desired curve number - ie - $K_a = 0$ and $K_b = K_j$. In equation 5 the curve number interval extends from the desired curve number K_i to the maximum curve number in the sample - ie - $K_a = K_i$ and $K_b = K_{max}$. Equations 4 and 5 have the advantage that they make use of observations outside the boundaries of the

intermediate band while equation 3 uses only observations within the intermediate band. Equations 4 and 5 have the disadvantage that they are only true in the vacinity of the boundaries. Figure 2 shows curves computed with these equations using sand-silt soil observations. Two curves are obtained depending on which equation is used, and the space between the two curves very nearly equals the 95% confidence band from Figure 1. Equation 5 is approximately true in the vacinity of the upper boundary and is entirely correct at and outside the upper boundary. Equation 4 has the same properties with respect to the lower boundary.

It was found that the interval method (Equation 3) yielded a highly irregular distribution with quite wide confidence intervals due to the small number of observations within each curve number interval, sometimes even for wide curve member intervals. On the other hand, the cumulative method which yield acceptable confidence limits was appropriate only in the vacinity of the boundaries. Equation 4 near the lower boundary and equation 5 near the upper boundary. Therefore it was decided to use Equation 4 to establish the erosion potential - curve number relationship near the lower boundary (0 to 20%) and Equation 5 near the upper boundary (80% to 100%). The remainder of the relationship to be established by connecting the above with a smooth curve which as near as possible followed the trend established by Equation 3. The procedure is shown in Figure 3.

There is no theoretical basis for this procedure, however it was used since it seemed to make the best use of the limited data.

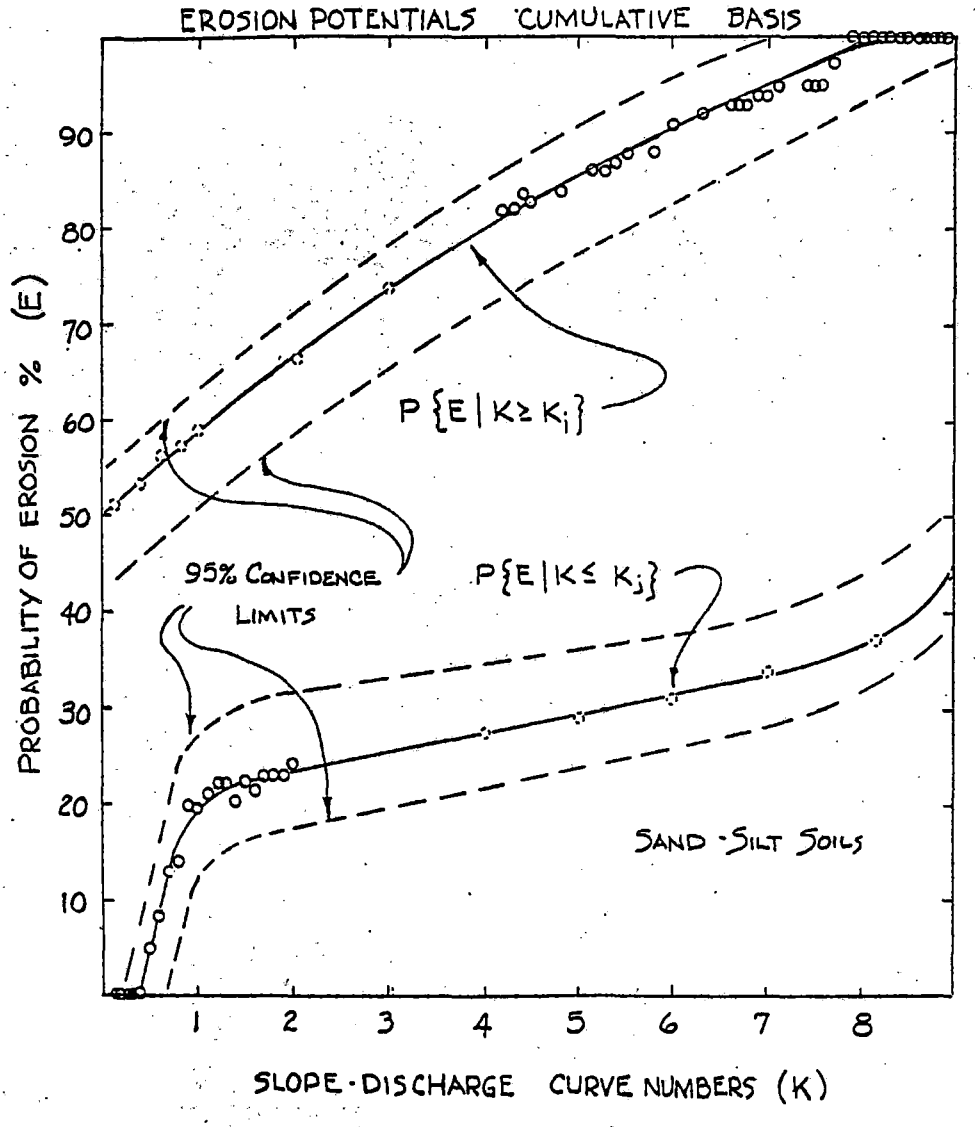

EROSION POTENTIALS CUMULATIVE BASIS
PROBABILITY OF EROSION % (E)
90
80
70
60
50
40
30
20
10
P{E|K≥Kᵢ}
95% CONFIDENCE LIMITS
P{E|K≤Kⱼ}
SAND-SILT SOILS
1
2
3
4
5
6
7
8
SLOPE-DISCHARGE CURVE NUMBERS (K)

Figure 2

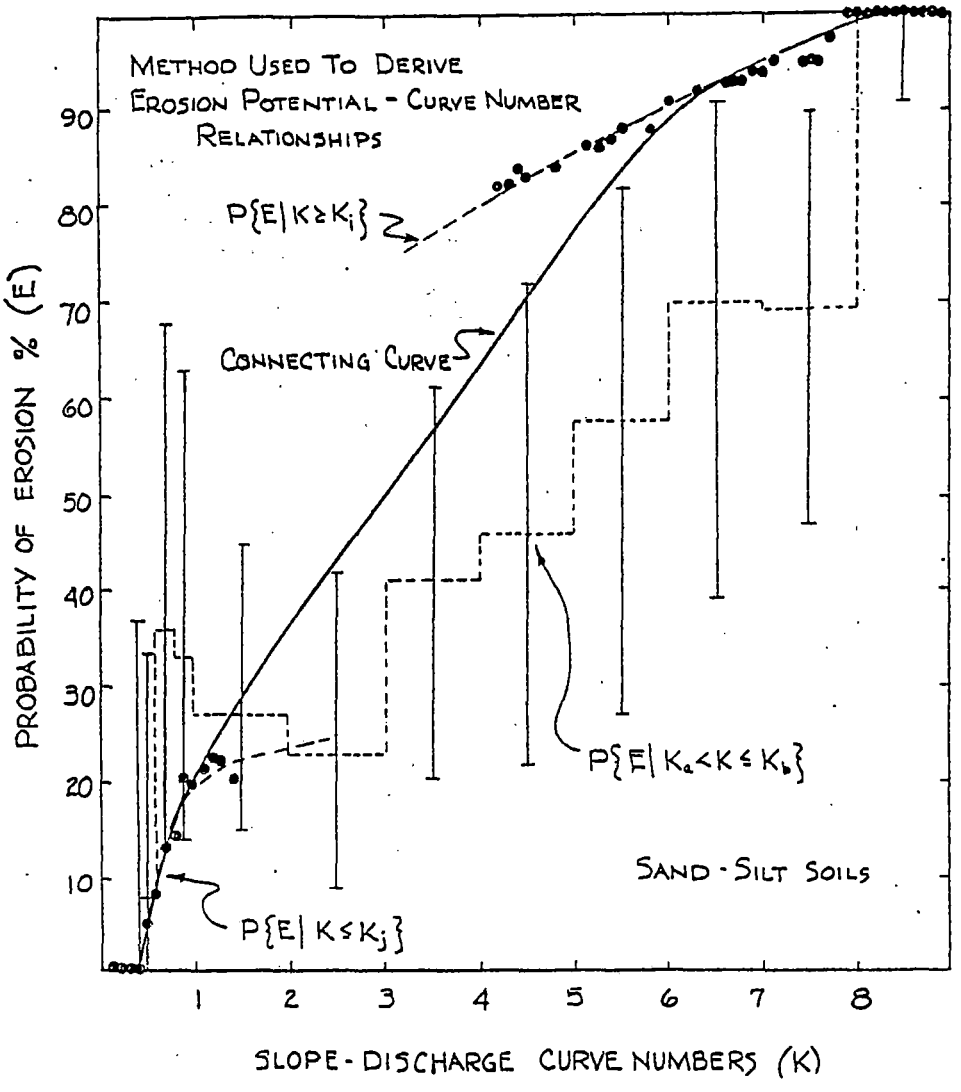

METHOD USED TO DERIVE
EROSION POTENTIAL - CURVE NUMBER
RELATIONSHIPS
P{E| K≥Kᵢ}
CONNECTING CURVE
P{E| Kₐ<K≤K_b}
P{E| K≤Kⱼ}
SAND - SILT SOILS
PROBABILITY OF EROSION % (E)
SLOPE - DISCHARGE CURVE NUMBERS (K)
10
20
30
40
50
60
70
80
90
1
2
3
4
5
6
7
8

Figure 3

D) Erosion Potentials - The family of erosion potential curves which constitute the intermediate region on the Keeley scatter diagrams can easily be established once the relationship between the probability of erosion and the associated curve number is known. The magnitude of an erosion potential is defined by the probability that erosion will occur. The location and shape of the erosion potential is defined by its associated curve number and Equation 1, or Equation 2, which describe the erosion potential curve in terms of the physical variables on the scatter diagram. Thus for any desired erosion potential, or probability of erosion, the appropriate curve number can be selected and used to compute the erosion potential curve on scatter diagram. Scatter diagrams on which the intermediate band has been defined by a family of erosion potential curves as described above will be referred to as erosion potential diagrams through the remainder of this report.

E) Erosion Risk Index - When investigating a particular reach of a stream channel, the soil characteristics of the bed and banks, as well as the channel slope are generally set by the physical characteristics of the region. That is slope and soil conditions are constant. The only erosion related variable then is discharge. A constant slope appears as a horizontal line on the appropriate erosion potential diagram (as dictated by soil conditions). The intersection of the horizontal (constant slope) line with a given discharge ordinate establishes an erosion potential which represents the probability of severe erosion on the condition that the particular value for discharge occurs. That is the erosion

potential is the conditional probability $P\{E|Q = q\}$. Whether or not a given magnitude of discharge occurs can be expressed in terms of probability using well established flood frequency procedures. However, these procedures yield an exceedence probability, $P\{Q \leq q\}$, which can be used to approximate $P\{Q = q\}$ as follows:

$$P\{q_a > Q \geq q_b\} = P\{Q \geq q_a\} - P\{Q \geq q_b\} \quad \ldots\ldots\ldots\ldots \quad (6a)$$

and

$$P\{q_a > Q \geq q_b\} = P\{Q = \bar{q}\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6b)$$

where

$$\bar{q} = 1/2 \left[q_a + q_b \right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6c)$$

The probability that a particular magnitude of discharge occurs, and that it causes severe erosion in the channel is given by:

$$P\{E \ \& \ Q = \bar{q}\} = P\{E|Q = \bar{q}\} \times P\{Q = \bar{q}\} \quad \ldots\ldots\ldots\ldots\ldots \quad (7)$$

Erosion is not caused by a single magnitude of discharge but may result from any of many different discharges, each of which is associated with a different erosion potential and has its own probability of occurance. That is, severe erosion could result from 100 cfs and an erosion potential of 90% or 10 cfs and an erosion potential of 20% or any of a number of other combinations. Thus the probability, or risk, of erosion is the sum of all these possible combinations.

$$\text{Erosion Risk Index} = \Sigma \, P\{E \ \& \ Q = \bar{q}\} \ (\Sigma \text{ from } \bar{q} = 0 \text{ to } \bar{q} = q_N) \ \ldots \quad (8)$$

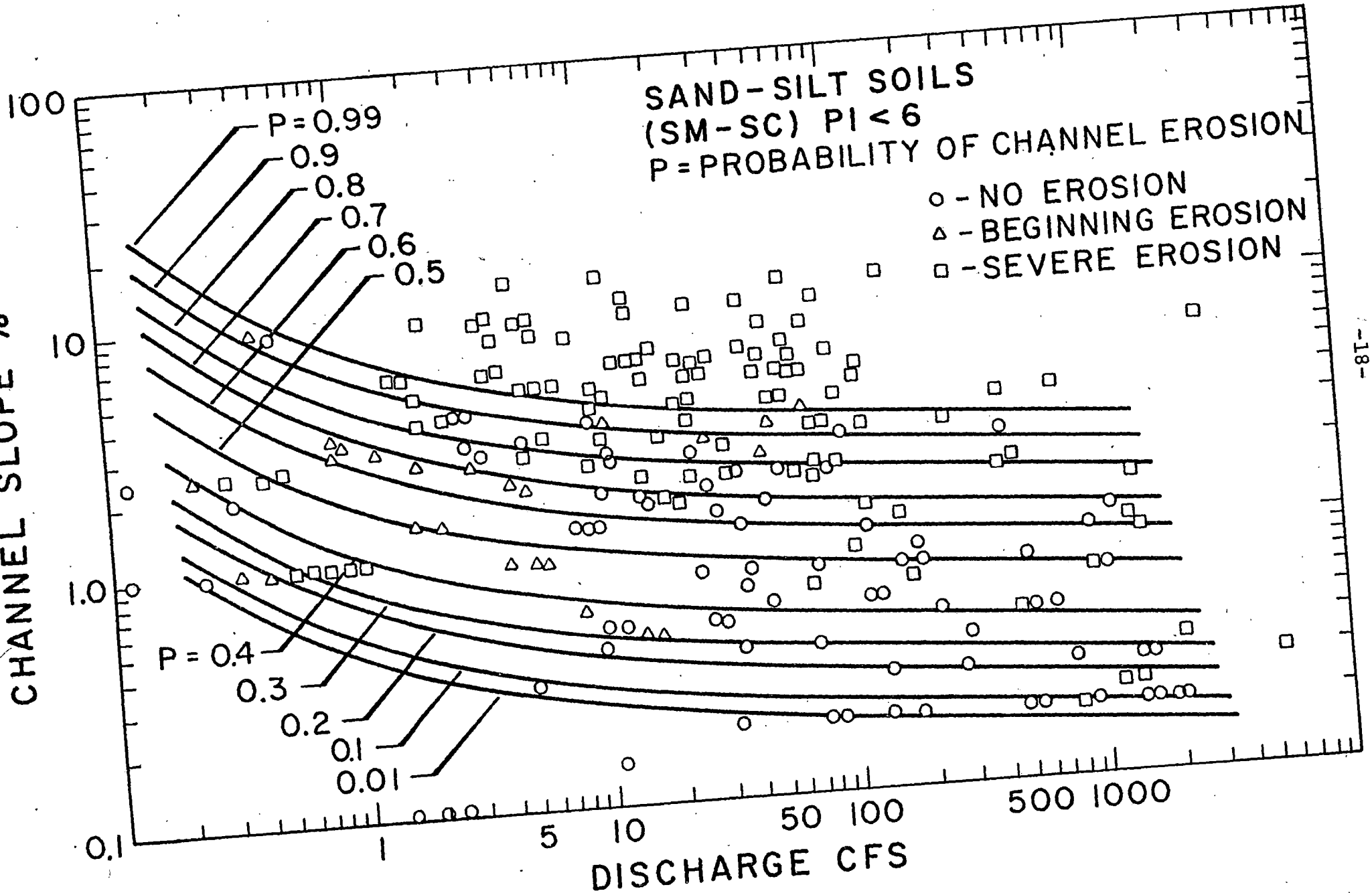
where $P\{E \ \& \ Q = \bar{q}\}$ is given by Equation 7 and q_N is an arbitrarily large discharge with very low probability of being equaled or exceeded.

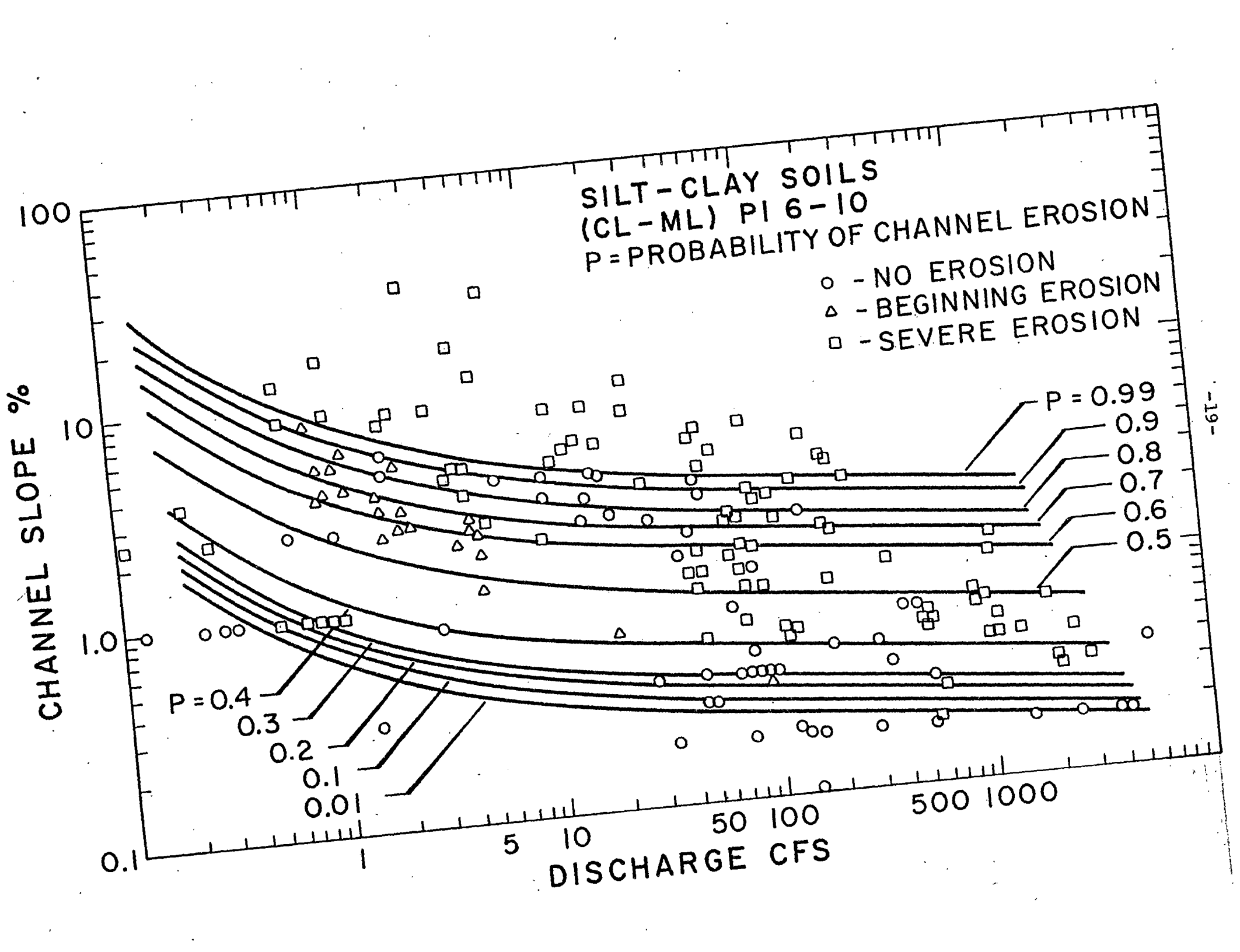
V. RESULTS

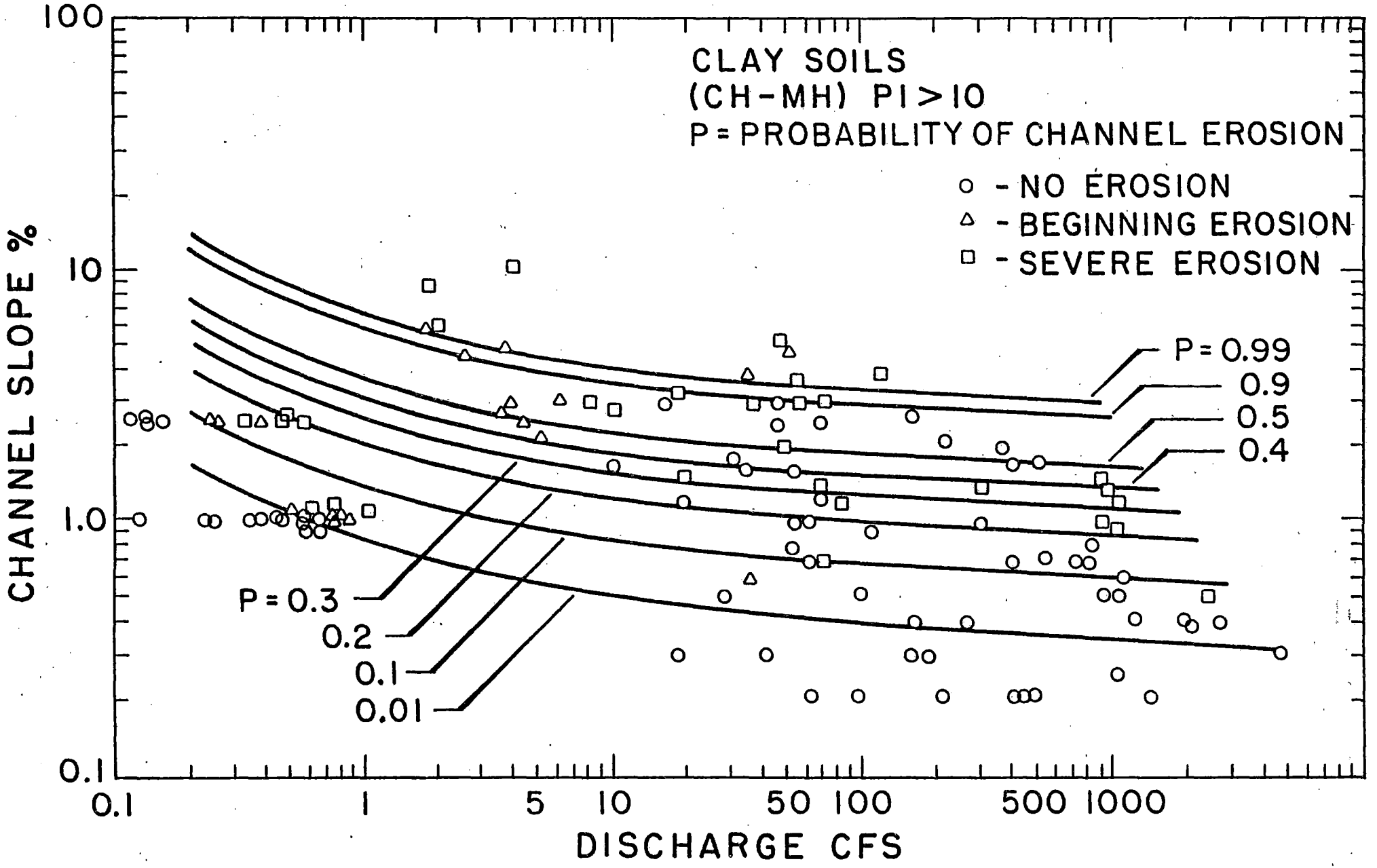
The many hours of field work and analysis involved in this study were compressed into the eight erosion potential diagrams shown in the next section. In addition to these diagrams, which are the results of the study, there is a brief discussion of the statistical reliability of the erosion potential diagrams and several examples showing how the erosion potential diagrams can be used to compute an erosion risk index.

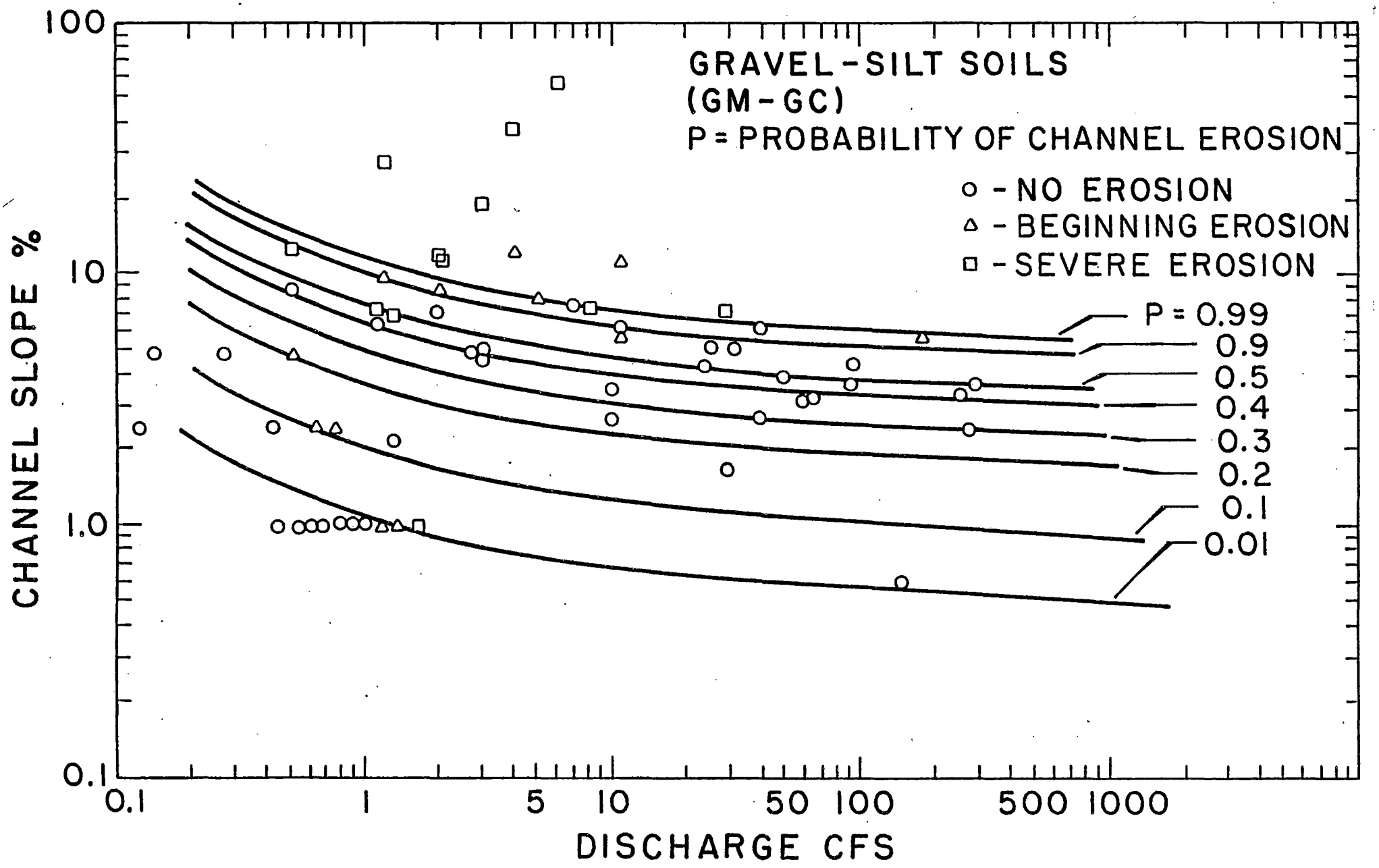
The erosion frequency curves used to derive the erosion potential diagrams are included in Appendix D of this report. Keeley's scatter diagrams are in Appendix C and the data collected during the course of this study is in Appendix B of this report.

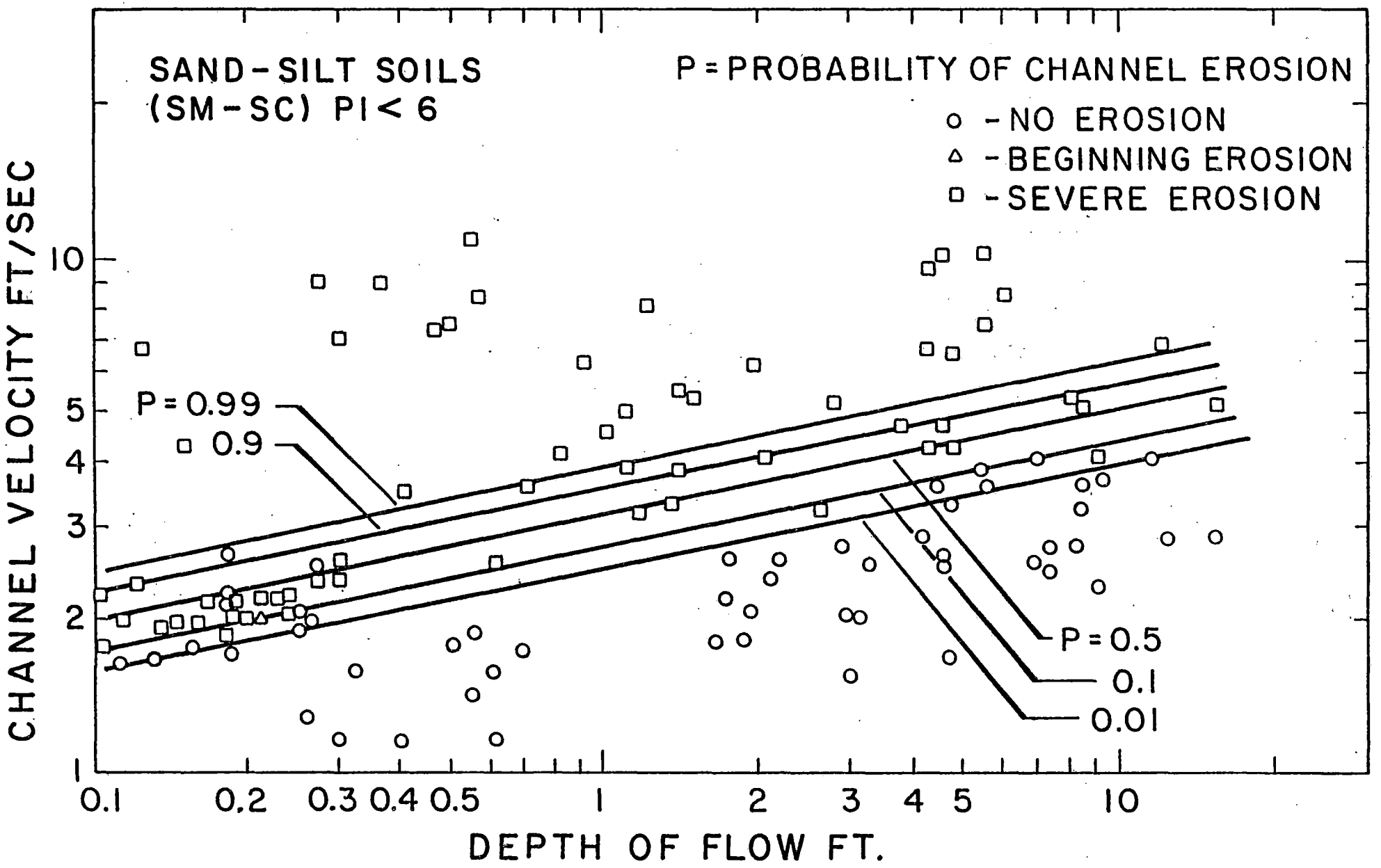
A) Erosion Potential Diagrams - These diagrams are essentially Keeley's scatter diagrams with added data and the family of erosion potentials superimposed on the data. There are two diagrams for each of the four soil classifications - sand-silt, silt-clay, clay and gravel-silt. The first set of diagrams have channel slope and discharge as variables and the second set have normal depth and normal velocity as variables. The former are the most convenient diagrams to use for determining an erosion risk index and will probably be the most useful. The second set of diagrams, which provide essentially the same information as the first, have been included to allow channel geometry to be considered where anticipated channel modifications may require or may allow such changes.

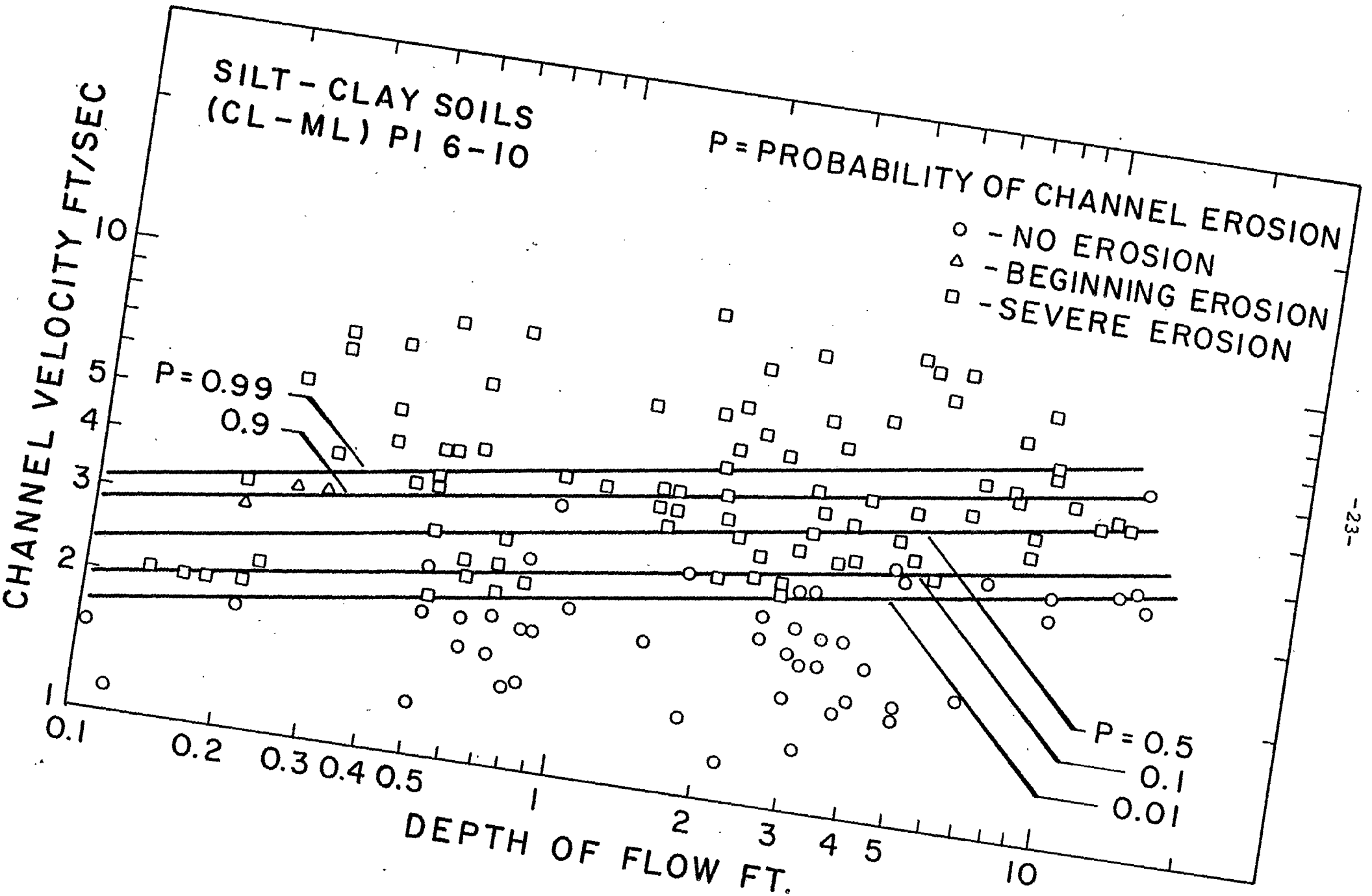

SAND-SILT SOILS
(SM-SC) PI < 6
P = PROBABILITY OF CHANNEL EROSION
o - NO EROSION
Δ - BEGINNING EROSION
□ - SEVERE EROSION
P = 0.99
0.9
0.8
0.7
0.6
0.5
P = 0.4
0.3
0.2
0.1
0.01
CHANNEL SLOPE %
100
10
1.0
0.1
1
5
10
50
100
500
1000
DISCHARGE CFS

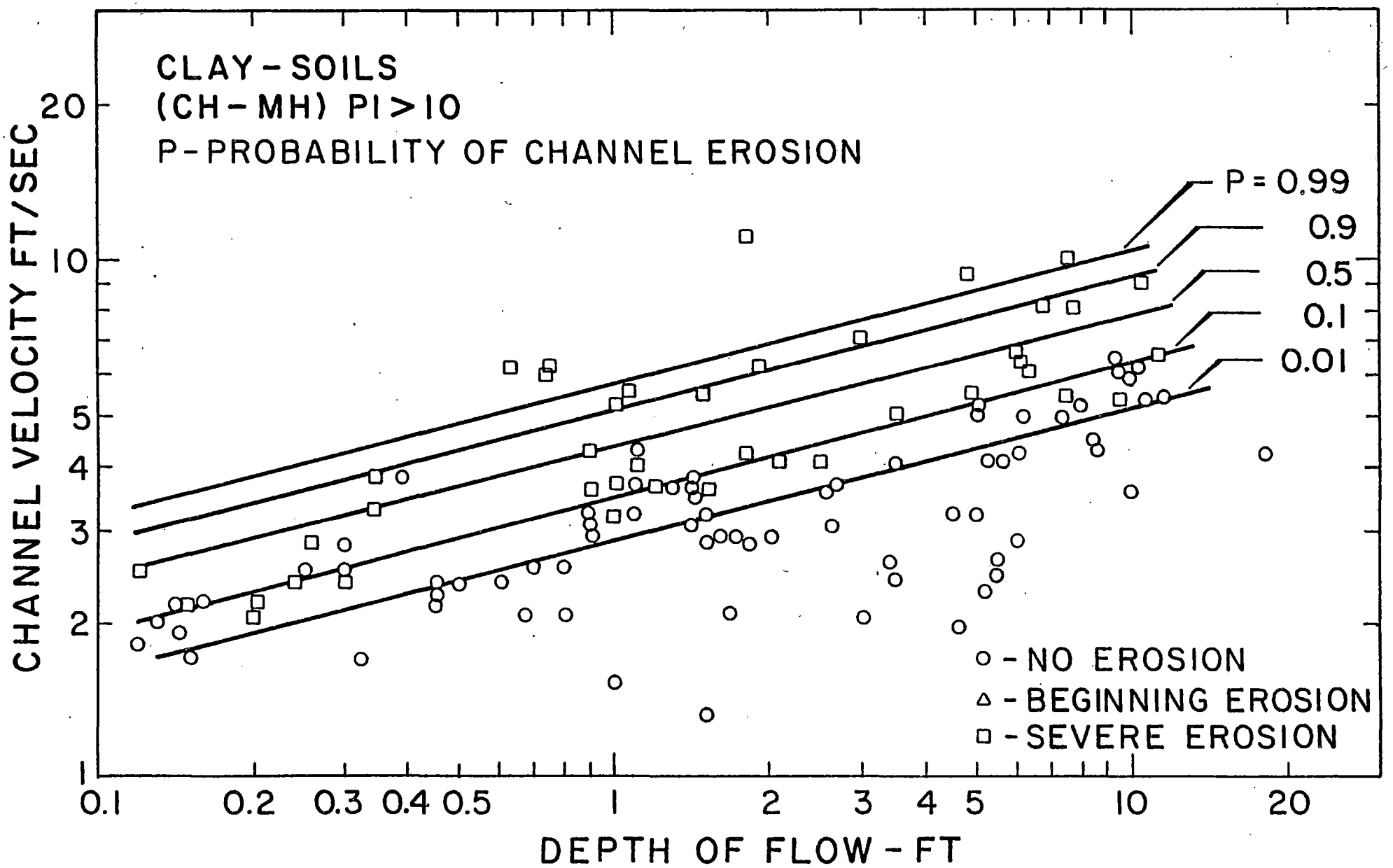

SILT-CLAY SOILS
(CL-ML) PI 6-10
P = PROBABILITY OF CHANNEL EROSION
○ - NO EROSION
△ - BEGINNING EROSION
□ - SEVERE EROSION
P = 0.99
0.9
0.8
0.7
0.6
0.5
P = 0.4
0.3
0.2
0.1
0.01
CHANNEL SLOPE %
100
10
1.0
0.1
1
5
10
50
100
500
1000
DISCHARGE CFS

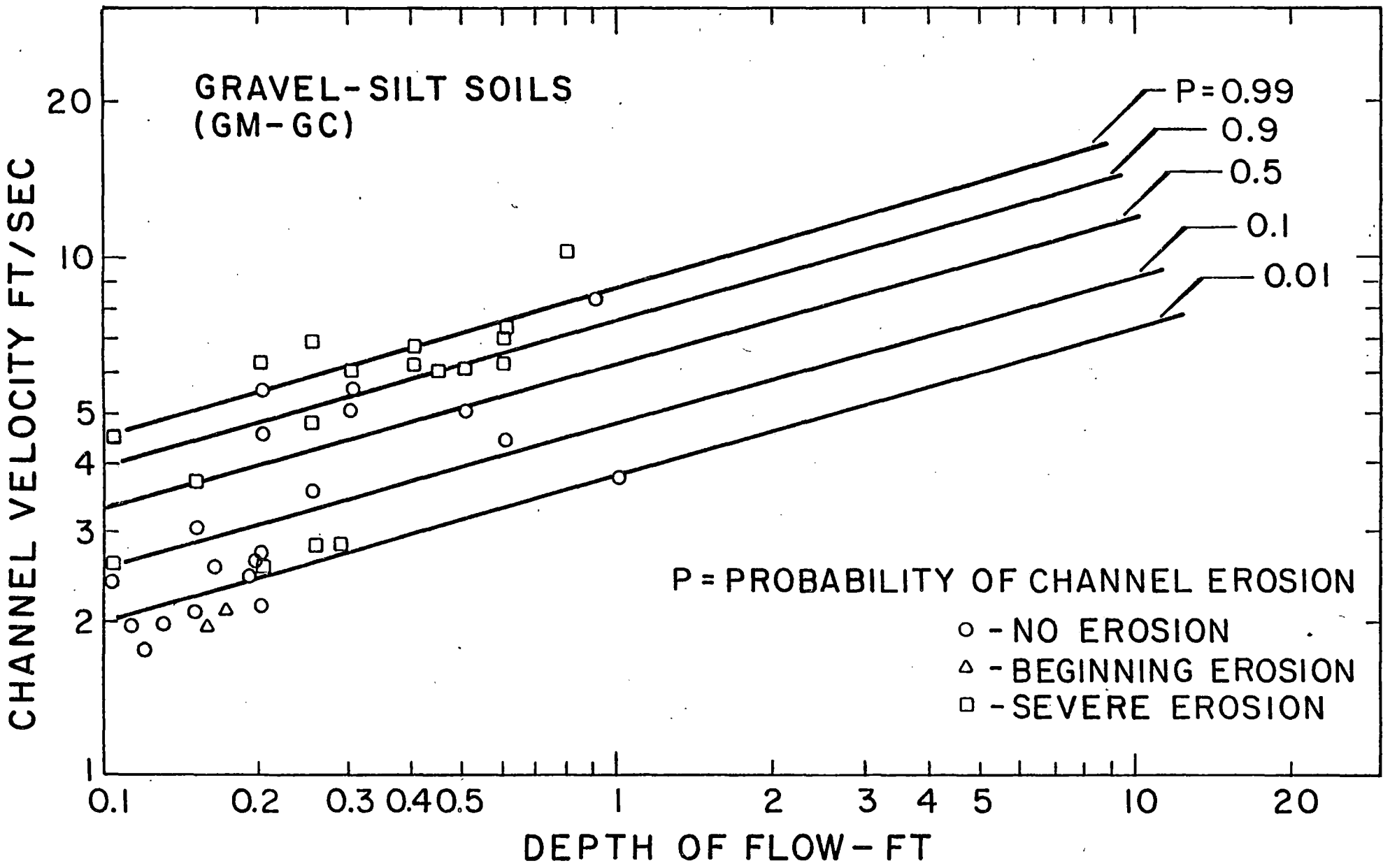

CLAY SOILS
(CH-MH) PI > 10
P = PROBABILITY OF CHANNEL EROSION
○ - NO EROSION
△ - BEGINNING EROSION
□ - SEVERE EROSION
P = 0.99
0.9
0.5
0.4
P = 0.3
0.2
0.1
0.01
CHANNEL SLOPE %
100
10
1.0
0.1
0.1
1
5
10
50
100
500
1000
DISCHARGE CFS


GRAVEL-SILT SOILS
(GM-GC)
P = PROBABILITY OF CHANNEL EROSION
○ - NO EROSION
△ - BEGINNING EROSION
□ - SEVERE EROSION
P = 0.99
0.9
0.5
0.4
0.3
0.2
0.1
0.01
CHANNEL SLOPE %
100
10
1.0
0.1
0.1
1
5
10
50
100
500
1000
DISCHARGE CFS


SAND-SILT SOILS
(SM-SC) PI < 6
P = PROBABILITY OF CHANNEL EROSION
o - NO EROSION
Δ - BEGINNING EROSION
□ - SEVERE EROSION
P = 0.99
0.9
P = 0.5
0.1
0.01
CHANNEL VELOCITY FT/SEC
DEPTH OF FLOW FT.
1
2
3
4
5
10
0.1
0.2
0.3
0.4
0.5
1
2
3
4
5
10


SILT - CLAY SOILS
(CL - ML) PI 6 - 10
P = PROBABILITY OF CHANNEL EROSION
○ - NO EROSION
△ - BEGINNING EROSION
□ - SEVERE EROSION
CHANNEL VELOCITY FT/SEC
DEPTH OF FLOW FT.
P = 0.99
0.9
P = 0.5
0.1
0.01
1
2
3
4
5
10
0.1
0.2
0.3
0.4
0.5


CLAY - SOILS
(CH - MH) PI > 10
P - PROBABILITY OF CHANNEL EROSION
P = 0.99
0.9
0.5
0.1
0.01
o - NO EROSION
Δ - BEGINNING EROSION
□ - SEVERE EROSION
CHANNEL VELOCITY FT/SEC
DEPTH OF FLOW - FT
20
10
5
4
3
2
1
0.1
0.2
0.3
0.4
0.5
1
2
3
4
5
10
20


GRAVEL-SILT SOILS
(GM-GC)
P=0.99
0.9
0.5
0.1
0.01
P = PROBABILITY OF CHANNEL EROSION
○ - NO EROSION
△ - BEGINNING EROSION
□ - SEVERE EROSION
CHANNEL VELOCITY FT/SEC
DEPTH OF FLOW - FT
1
2
3
4
5
10
20
0.1
0.2
0.3
0.4
0.5
1
2
3
4
5
10
20

A word of caution with respect to the second set of diagrams. The computation procedure for finding an erosion risk index using these diagrams is highly sensitive to the selection of Mannings n and should be used only when n is reliably known.

A further word of caution about using the second set of diagrams at culvert exits is in order. Keeley found, and the field observations made during the course of this study verified, that erosion at a culvert exit does not correlate well with culvert exit velocity. Erosion at a culvert exit is apparently a function of a complex combination of several variables, one of which is exit velocity. It is recommended that if the second set of erosion potential diagrams are used at a culvert exit, the velocity and depth used to enter the diagram be computed by averaging the culvert exit values with channel normal depth and velocity. The recommended method, which is illustrated in the fourth example in this section of the report, has no theoretical basis, but is an attempt to recognize the emperical evidence which suggests that culvert exit velocities overstate the possibility of erosion while normal velocity for the downstream channel probably understates the possibility of erosion at a culvert site.

B) Reliability - Little can be said about reliability of erosion potentials on the interior of the intermediate region since their location is mainly a matter of spacing interior curves between the boundaries as dictated by the erosion potential-curve number relationship. Interior curves are not unimportant but it is boundary regions which are of greatest importance.

The interior erosion potential curves could be spaced with high degree of precision but would be completely wrong if intermediate band itself was misplaced. The boundary region is considered to be the 90% to 99% erosion potentials at upper boundary and the 1% to 10% erosion potentials at lower boundary. The upper 99% erosion potential was located between the largest curve number for which there was a non-erosion observation and the next higher observed curve number.

The following table indicates the degree of confidence, or the probability, that the boundary curve number has an associated erosion potential of either greater than 90% (upper boundary) or less than 10% (lower boundary).

SLOPE-DISCHARGE SCATTER DIAGRAMS

Upper Boundary

Soil	Probability boundary erosion potential ≥ 0.90	Number observations above boundary	Total number observations
Sand-Silt	99 + %	55	222
Silt-Clay	98%	39	172
Clay	60%	7	124
Gravel-Silt	62%	8	62

Lower Boundary

Soil	Probability boundary erosion potential ≤ 0.10	Number observations below boundary	Total number observations
Sand-Silt	85%	18	222
Silt-Clay	82%	15	172
Clay	96%	33	124
Gravel-Silt	65%	9	62

Roughly speaking one can say that the confidence level associated with the location of the upper boundaries on the sand-silt and silt-clay erosion potential diagrams exceeds 95% while the confidence level associated with the location of the lower boundaries on these diagrams is about 85%. Similarly the confidence level associated with the locations of both the upper and lower boundaries on the gravel silt erosion potential diagram is only about 65%. The confidence level associated with the lower boundary on the clay erosion potential diagram exceeds 95% but because of the few observations in the assured erosion region the upper boundary can be located with only a 60% confidence level.

The following table shows similar information for velocity-depth scatter diagrams. An additional indication of the reliability of these diagrams, and by implication the slope-discharge diagrams since they are based on same observations, is that the lower boundaries of these diagrams agree with the Fortier-Scoby permissible velocity for similar soil conditions. Permissible velocities should be lower bounding values since they should be maximum values which assure no erosion.

DEPTH-VELOCITY SCATTER DIAGRAMS

Upper Boundary

Soil	Probability boundary erosion potential ≥ 0.90	Number observations above boundary	Total observations
Sand-Silt	95%	30	117
Silt-Clay	97%	36	140
Clay	60%	7	115
Gravel-Silt	52%	5	26

Lower Boundary

Soil	Probability boundary erosion potential ≤ 0.10	Number observations below boundary	Total observations
Sand-Silt	99%	40	117
Silt-Clay	99%	39	140
Clay	99 + %	50	115
Gravel-Silt	75%	12	26

C) Erosion Risk Index Examples

Example No. 1

Given: A small drainage channel with sandy-silt bed and banks, and a bed slope of 3%

Discharge cfs	Recurrence Interval years	Exceedence Probability %
26	100	1
16	20	5
12	10	10
7.5	4	25
4.5	2	50
3.0	1.33	75
2.0	1.11	90
1.0	1.02	98

Find: The erosion risk index for the given information.

(1) Equations:

$$\text{Erosion Risk Index} = \Sigma P\{E \ \& \ Q = \bar{q}\} \quad \ldots\ldots\ldots\ldots\ldots \quad (8)$$

$$P\{E \ \& \ Q = \bar{q}\} = P\{E|Q = \bar{q}\} \times P\{Q = \bar{q}\} \quad \ldots\ldots\ldots\ldots \quad (7)$$

$$P\{Q = \bar{q}\} \cong P\{Q\ q_a\} - P\{Q \geq q_b\} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

(2) $P\{E|Q = \bar{q}\}$ is the erosion potential from the sand-silt erosion potential diagram with a constant channel slope of 3%.

(3) Computations

Q	$\bar{q}$	$P\{Q \geq \bar{q}\}$	$P\{Q = \bar{q}\}$	$P\{E|Q = \bar{q}\}$	$P\{E \ \& \ Q = \bar{q}\}$
26		0.01			
	21		0.04	0.90	.036
16		0.05			
	14		0.05	0.89	.045
12		0.10			
	9.8		0.15	0.88	.132
7.5		0.25			
	6.0		0.25	0.84	.210
4.5		0.50			
	3.8		0.25	0.80	.200
3.0		0.75			
	2.5		0.15	0.78	.117
2.0		0.90			
	1.5		0.08	0.70	.056
1.0		0.98			

$\Sigma = .796$.

Column 2 in the previous table is the mean value of Q for the two adjacent values from Column 1, - eg - $\frac{1}{2}[16+26] = 21$ etc. Column 3 is the exceedence probability associated with each discharge in Column 1. Column 4 is computed using equation 6 and Column 3 - eg - 0.04 = 0.05 - 0.01 etc. Column 5 are erosion potentials from the sand-silt diagram with a constant slope of 3% and the values of $\bar{q}$ from Column 2. Column 6 is equation 7 - eg - .036 = (.9) x (.04) etc. The erosion risk index according to equation 8 is the sum of Column 6 or about 80%. What this means is that for the conditions specified there are 8 chances out of 10 that severe erosion will occur in this reach of channel in any given year. Note, this assumes bare soil with no grass or other channel protection. Grass or other protective vegetation in the channel would greatly diminish the probability of erosion. The erosion risk index can also be determined by finding the area under a plot of $P\{Q - \bar{q}\}$ versus $P\{E|Q = \bar{q}\}$. This method is more accurate than the tabular method, however the minor increase in accuracy hardly warrants the added time required.

Example No. 2

Given: The data from Example No. 1, except that the channel slope is 0.5%.

Find: (a) The erosion risk index.

(b) The risk of erosion during a 10 year period.

All information is the same as Example 1 except $P\{E|Q = \bar{q}\}$ which now must be found for a slope of 0.5%

Erosion Risk Index = (0.04) (0.36) + (0.05) (0.33) + (0.15) (0.30) + (0.25) (0.29) + (0.25) (0.21) + (0.15) (0.19) + (0.08) (0.15) = 0.24.

The erosion risk index is 0.24, or there is about one chance in four that severe erosion will occur in any given year.

The probability that erosion will not occur in a 10 year period can be found using the binomial equation, which reduces to:

$$P\{\text{erosion will occur exactly zero times}\} = (1-P)^n$$

Therefore, the probability that no erosion will occur in ten years is $(1-.24)^{10} = 0.064$ and finally the probability that severe erosion will occur one or more times in 10 years is (1 - 0.064) = 0.936. Thus, even though there is only one chance in four that erosion will occur in any given year, it is highly probable that severe erosion will occur at least once in ten years. Once again this assumes no protective cover develops during that period.

Example No. 3

Given: Data the same as Example No. 2. The channel cross section is trapezoidal with 2:1 side slopes and a 6 foot bottom width. Assume n = .025.

Find: The erosion risk index using the normal velocity - normal depth erosion potential diagram.

$\bar{q}$	V_n	Y_n	$P\{V_n,Y_n\}$	$P\{E\|V_n,Y_n\}$	$P\{E \& V_n,Y_n\}$
21	3.2	0.95	.04	.60	.024
14	2.9	0.7	.05	.45	.023
9.8	2.6	0.6	.15	.20	.030
6.0	2.2	0.4	.25	.08	.020
3.8	1.9	0.3	.25	.01	.003
2.5	1.5	0.2	.15	0	--
1.5	1.2	0.15	.08	0	--

$\Sigma = 0.10$

Column 4 assumes that the probability of the given normal velocity and depth is the same as the probability of the associated discharge, $\bar{q}$. Column 5 lists erosion potentials from the depth - velocity erosion potential diagram for sand-silt. As was done in earlier examples, column 6 is the product of columns 4 and 5. The summation of column 6 is the desired erosion risk index which is 0.10. The difference between this erosion risk index and the similar value from example two is due primarily to the selection of the roughness coefficient n. As an example of the sensitivity of this procedure to the selection of n, the same calculations using n = 0.20 yields an erosion risk index of 0.28.

Example No. 4

Given: A 24 inch CMP with projecting entrance is set on a 0.5% slope. The flow data is the same as Example No. 1 and the downstream channel cross-section is the same as Example No. 3. The downstream channel has a slope of 0.5%. Assume critical depth at the culvert exit.

	Culvert Exit		Channel		Mean				
$\bar{q}$	V	Y	V_n	Y_n	V	Y	P{E|V,Y}	P{V,Y}	P{E & V,Y}
21	8	12	3.2	0.9	5.6	1.5	1.0	.04	.04
14	7.6	1.7	2.9	0.7	5.3	1.2	1.0	.05	.05
9.8	6.4	1.4	2.6	0.6	4.5	1.0	1.0	.15	.15
6.0	5.0	1.0	2.2	0.4	3.6	0.7	.99	.25	.24
3.8	4.0	0.7	1.9	0.3	3.0	0.5	.80	.25	.20
2.5	3.4	0.5	1.5	0.2	2.5	0.35	.40	.15	.06
1.5	2.4	0.3	1.2	0.15	1.8	0.23	.01	.08	--

$\Sigma = .74$

The suggested method has no basis in theory but seems a good compromise since conditions at the culvert exit overstate the potential for erosion while the channel normal depth and velocity understate the possibility of erosion at the culvert exit. Had the culvert exit velocity and depth been used, the erosion risk index would have been close to one.

VI. CONCLUSIONS

A) With possible exception of the precise location of interior erosion potentials the method described here provides a theoretically sound way to estimate the risk of severe erosion in stream channel.

B) This method will not replace an extensive erosion survey but ~~was not intended to do so. It~~ does provide a quick method to estimate the erosion risk in a stream channel using easily obtained data.

C) The sand-silt, silt-clay and clay erosion potential diagrams have an acceptable degree of statistical reliability although upper boundary on clay erosion potential diagram is

somewhat questionable. The gravel-silt erosion potential diagrams are of marginal statistical reliability.

D) The erosion risk index computed with the normal depth-normal velocity erosion potential diagrams is highly sensitive to small variations in the Manning roughness coefficient.

E) The erosion potential diagrams, as well as resulting erosion risk indexes, are valid for bare soil conditions only. A possible means for incorporating the effects of a grass cover, would be to reduce the velocity on the depth - velocity erosion potential diagram by the linear ratio of the permissible velocity on bare soil to the permissible velocity with appropriate grass cover.

APPENDIX A - REFERENCES

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APPENDIX B - DATA

Summarized field notes and laboratory observations are tabulated in this appendix.

FIELD OBSERVATIONS

DATA INDEX NO.	LATITUDE	LONG.	SOIL CLASS.	SOIL I.D. METHOD	CHANNEL BED SLOPE	DISCHARGE cfs	DISCHARGE EST. METH.	EROSION CONDITION
1	40°-22'	105°-27'	Fine Sand	Lab. Anal.	12.5%	60	Slope-Area	Significant scour down to bed rock
2	40°-22'	105°-27'	Fine Sand	"	12%	150	"	"
3	40°-22'	105°-27'	Soft shale	"	12%	150	"	little or no scour
4	40°-22'	105°-26'	Fine Sand	"	6.9%	3000	"	Significant scour to bed rock
5	40°-20'	105°-26'	Fine Sand	"	4%	15000	est. from cfs/sq mi drainage	No scour
6	40°-20'	105°-26'	Fine Sand	"	4%	22000		Begin Scour
7	39°-55'	105°-10'	Silt	Field estimate	9%	1	Slope-Area	Silt highly eroded
8	39°-58'	105°16'	Soft Shale	"	10%	150	Culvert	Highly eroded
9	36°-21'	104°-35'	Clay-Silt (PI)	"	0.3%	41	USGS Gage	No recent erosion
10	35°-48'	104°-58'	Silt	"	0.3%	1100	"	" " "
11	35°-35'	105°-12'	Silty Sand	"	0.4%	114	"	" " "
12	35°-24'	105°-31'	Silty Clay (PI)	"	0.3%	504	"	" " "
13	35°-7'	106°-37'	Fine Sand	"	2.0%	500	Culvert	Severe erosion
14	35°-7'	106°-37'	Fine Sand	"	4.7%	1.9	Slope-Area	" "
15	35°-7'	106°-37'	" "	"	1.9%	1.9	"	stable
16	35°-10'	106°-37'	Silty Sand	"	0.4%	10	Culvert	"
17	34°57'	106°39'	Silty Sand	"	2.7%	45	"	stable
18	34°59'	106°39'	" "	"	3.9%	70	"	Beginning of erosion
19	35°	106°-39'	Fine Sand	"	8.3%	~~50~~ 30	"	erosion in Channel
20	35°	106°-39'	" "	"	6.8%	40	~~Culvert~~ "	Beginning of erosion
21	35°	106°-37'	Silty Sand	"	0.6%	200	USGS gage	Stable
22	35°-3'	106°-38'	Silty Sand	"	5.7%	27	Culvert	"
23	35°-3'	106°-38'	Sand	"	5.3%	60	"	"
24	35°-3'	106°-38'	Sand	"	8.1%	8	Slope-Area	eroded
25	35°16'	106°37'	Fine Sand	"	2%	50	Culvert	stable
26	35°16'	106°-37'	" "	"	3.3%	0.33	Slope-Area	eroded
27	"	"	" "	"	2.0%	"	"	stable
28	35°-17'	106°-36'	" "	"	2.2%	80	Culvert	stable
29	35°18'	106°-35'	" "	"	2.8%	100	"	eroded
30	35°-19'	106°-34'	" "	"	2.4%	45	"	Beginning of erosion
31	35°-20'	106°-34'	" "	"	0.6%	35	"	stable

FIELD OBSERVATIONS

DATA INDEX NO.	LATITUDE	LONG.	SOIL CLASS.	SOIL I.D. METHOD	CHANNEL BED SLOPE	DISCHARGE CFS	DISCHARGE EST. METHOD	EROSION CONDITION
32	35°-22'	106°-37'	Fine Sand	Field estimate	2.8%	28	Culvert	Begining of erosion
33	35°-22'	106°-37'	Silty Sand	"	3.9%	1.9	Slope-Area	eroded channel
34	"	"	"	"	2.4%	1.9	"	stable
35	35°-24'	106°-38'	Fine Sand	"	2.0%	35	Culvert	stable
36	35°-29'	106°-41'	"	"	1.5%	48	"	stable
37	35°-28'	106°-39'	"	"	1.4%	30	"	stable
38	35°-18'	106°-30'	Sandy Silt	"	3.7%	11	"	stable
39	35°-18'	106°-30'	" "	"	14.%	11	"	highly eroded
40	35°-18'	106°-28'	Gravel-Silt	"	12.%	11	"	Begining of erosion
41	35°-18'	106°-28'	"	"	6.%	11	"	stable
42	35°-18'	106°-28'	Gravel Silt	"	3.9%	300	"	stable
43	35°-18'	106°-27'	Gravel Sand	"	3.4%	260	"	"
44	35°-18'	106°-26'	Clay-Silt	"	7.8%	11	"	"
45	35°-18'	106°-26'	Soft Sandstone	"	10 %	20	"	eroded
46	35°-6'	106°-23'	Silty Sand	"	3.8%	420	"	eroded
47	35°-7'	106°-24'	Sandy Silt	"	1.3%	8	"	stable
48	35°-8'	106°-23'	Silt some Clay	"	2.2%	15	"	stable
49	35°-8'	106°-23'	Silt some Clay	"	3.6%	0.2	Slope Area	eroded
50	35°-9'	106°-22'	Gravel-Silt	"	6 %	180	Culvert	stable
51	35°-10'	106°-21'	Silt	"	1.7%	110	"	Begining of erosion
52	35°-11'	106°-20'	Silt	"	6%	50	"	extensive scour
53	35°-11'	106°-20'	gravel-Silt	"	5.4%	31	"	stable
54	35°-12'	106°-19'	gravel Silt	"	0.6%	150	"	stable
55	35°-12'	106°-18'	Gravel-Silt	"	7.5%	8	"	eroded
56	35°-13'	106°-17'	Gravel-Silt	"	8.0%	7	"	stable
57	35°-14'	106°-16'	Silt	"	4.6%	140	"	stable
58	35°-14'	106°-16'	Silt	"	3.7%	49	"	stable
59	35°-15'	106°-15'	gravel-Silt	"	2.5%	280	"	stable
60	35°-16'	106°-14'	Silt	"	8.3%	45		eroded
61	35°-17'	106°-14'	Gravel-Silt	"	6.4%	40	"	stable
62	35°-20'	106°-14'	Sandy-Silt	"	5.8%	26	"	eroded

FIELD OBSERVATIONS

DATA INDEX NO.	LATITUDE	LONG.	SOIL CLASS	SOIL I.D. METHOD	CHANNEL BED SLOPE	DISCHARGE cfs	DISCHARGE EST. METHOD	EROSION CONDITION
63	35°-22'	106°-15'	Sandy-Silt	Field estimate	4.3%	11	Culvert	eroded
64	35°-23'	106°-16'	Sandy-Silt	"	10.6%	14	"	eroded
65	35°-24'	106°-17'	Silty-Sand	"	3.7%	9	"	stable
66	35°-25'	106°-17'	Silty-Sand	"	2.5%	24	"	stable
67	35°-26'	106°-18'	Silty-Sand	"	1.2%	38	"	stable
68	35°-27'	106°-18'	Silty-Sand	"	2.5%	11	"	stable
69	35°-8'	106°-30'	Gravel-Silt	"	4.6%	24	"	stable
70	35°-8'	106°-30'	Gravel-Silt	"	3.3%	60	"	eroded
71	35°-9'	106°-30'	Gravel-Silt	"	1.7%	29	"	stable
72	35°-9'	106°-30'	Gravel-Silt	"	7.3%	29	"	eroded
73	35°-9'	106°-30'	"	"	3.3%	66	"	stable
74	35°-10'	106°-30'	"	"	4.0%	80	"	stable
75	35°-10'	106°-30'	"	"	2.8%	40	"	stable
76	35°-11'	106°-30'	"	"	3.8%	95	"	stable
77	35°-12'	106°-30'	"	"	3.6%	10	"	stable
78	35°-12'	106°-30'	"	"	5.4%	25	"	stable
79	35°-12'	106°-31'	"	"	4.6%	95	"	stable
80	35°-12'	106°-31'	"	"	6.4%	11	"	"
81	35°-12'	106°-32'	"	"	2.8%	10	"	"
82	40°-8'	105°-15'	Fine Sandy Silt	"	0.8%	199	Measurment	"
83	40°-8'	105°-16'	Clay	"	6.2%	0.01	est.	"
84	40°-8'	105°-16'	clay	"	6.2%	2	Culvert	eroded
85	40°-8'	105°-16'	Silty clay	"	0.3%	1.4	Slope Area	stable
86	40°-9'	105°-17'	Silty clay	"	4.4%	11	Culvert	stable
87	40°-8'	105°-17'	Clay-Silt	"	7.5%	30	"	"
88	40°-7'	105°-17'	Silty clay	"	5.6%	14	"	"
89	40°-7'	105°-17'	Silty clay	"	8.9%	14	"	Begin erosion
90	40°-6'	105°-17'	Silty clay	"	7.3%	25	"	stable
91	40°-6'	105°-17'	Silty clay	"	8.3%	0.75	Slope-Area	stable
92	40°-5'	105°-17'	Silty clay	"	5.0%	13	Culvert	stable
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FIELD OBSERVATIONS

DATA INDEX NO	LAT.	LONG.	SOIL-CLASS	SOIL I.D. METH.	CHANNEL BED SLOPE	DISCHARGE CFS	DISCHARGE EST. METH.	EROSION CONDITION
94	39°-34'	104°-53'	Silty-Clay PI>6	Field Est.	1.5%	16	Culvert	stable
95	39°-34'	104°-53'	Silty-Clay PI>6	"	13.0%	0.6	Slope Area	Eroded
96	"	"	"	"	2.5%	0.6	"	stable (deposit)
97	39°-34'	104°-54'	"	"	2.1%	3.0	Culvert	Stable
98	39°-34'	104°-56'	"	"	5.6%	4.0	"	stable
99	39°-34'	104°-58'	"	"	4.7%	22.0	"	"
100	39°-34'	105°-5'	"	"	3.7%	1.0	Slope Area	stable
101	"	"	"	"	16.0%	1.0	"	eroded
102	39°-29'	105°-3'	Clay-Silt	"	1.7%	10	Culvert	stable
103	"	"	soft sand stone	"	1.7%	35	"	eroded
104	39°-26'	104°-55'	Sandy-Silt	"	1.8%	10	"	stable
105	39°-27'	104°-56'	"	"	0.5%	12	"	"
106	39°-28'	104°-55'	Silt some clay	"	3.6%	4	"	"
107	39°-29'	104°-55'	Silt	"	4.9%	10	"	"
108	39°-29'	104°-55'	"	"	6.8%	60	"	eroded
109	39°-31'	104°-56'	Silt-Clay PI>6	"	6.2%	2	"	stable
110	39°-32'	104°-56'	"	"	2.8%	8	"	"
111	39°-33'	104°-56'	"	"	1.4%	4	"	"
112	39°-36'	104°-54'	"	"	2.0%	150	"	"
113	39°-38'	104°-54'	"	"	4.6%	10	"	"
114	39°-31'	104°-52'	"	"	7.0%	45	"	"
115	"	"	"	"	9.6%	25	"	eroded
116	"	"	"	"	3.0%	10	"	stable
117	39°-29'	104°-52'	Silt Clay	"	3.5%	3	"	stable
118	39°-29	104°-52'	Silt-Clay PI>6	"	17.0%	4	"	scoured
119	"	"	Silt-Clay	"	1.9%	90	"	stable
120	39°-27'	104°-52'	Silty-Sand	"	1.1%	120	"	stable
121	39°-27'	104°-52'	"	"	1.3%	10	"	"
122	39°-29'	104°-52'	"	"	9.5%	11	"	"
123	39°-28'	104°-52'	"	"	8.3%	2	"	"
124	39°-22'	104°-51'	Silt-Clay PI>6	"	4.0%	60	"	"

FIELD OBSERVATIONS

DATA INDEX NO.	3 LAT.	2 LONG.	SOIL CLASS.	SOIL I.D. METHOD	CHANNEL BED SLOPE	DISCHARGE CFS	DISCHARGE EST. METH.	10 EROSION 11 CONDITION
125	39°-23'	104°-45'	Silty-Clay PI>6	Field Est.	0.8%	3	Culvert	stable
126	39°-26'	104°-46'	"	"	5.7%	5	"	"
127	39°-27'	104°-46'	"	"	2.2%	5	"	"
128	39°-27'	104°-46'	"	"	12.0%	5	"	Begining erosion
129	39°-27'	104°-46'	Sandy Silt	"	9.2%	5	"	scoured
130	39°-27'	104°-46'	"	"	9.0%	5	"	scoured
131	39°-27'	104°-47'	Silty Clay PI>6	"	5.8%	85	"	scoured
132	"	"	"	"	8.0%	11	"	stable
133	39°-26'	104°-48'	Silty Clay PI>6	"	30.0%	6	"	scoured
134	39°-26'	104°-50'	"	"	27%	20	"	stable
135	"	"	Silty Clay	"	4.0%	6	"	stable
136	"	"	Silty-Clay PI>6	"	3.6%	20	"	stable
137	39°-47'	104°-51'	Silty sand	"	0.8%	75	"	"
138	39°-48'	104°-51'	Silty Sand	"	0.8%	40	"	"
139	39°-49'	104°-50'	Silty Sand	"	0.3%	5	Slope Area	"
140	39°-44'	104°-49'	Silt-Clay PI>6	"	0.7%	140	MEASURED	"
141	39°-45'		Sandy Silt	"	1.7%	15	MEASURED	"
142	39°-47'	104°-56'	Silty Sand	"	20%	80	Culvert	eroded
143	39°-50'	105°-8'	Silty-Clay PI>6	"	1.2%	7	MEASURED	Stable
144	39°-49'	105°-3'	Sand/w gravel	"		99	"	"
145	39°-48'	105°-8'	Silty Clay PI>6	"		24	"	"
146	39°-48'	105°-8'	Sandy Silt	"	9.6%	4	CULVERT	eroded
147	39°-45'	104°-47'	Sandy Silt	"	0.5%	10	Guess	stable
148	39°-45'	105°	Sandy Silt	"	0.5%	30	MEASURED	stable
149	39°-32'	104°-53'	Silty Clay	"	2.6%	140	Culvert	stable
150	39°-32'	104°-52'	Silty Clay PI>6	"	0.8%	10	"	"
151	39°-32'	104°-51'	"	"	4.1%	18	"	"
152	39°-32'	104°-48'	Silty Clay	"	1.9%	14	"	"
153	39°-32'	104°-48'	"	"	2.3%	12	"	Stable
154	39°-31'	104°-47'	Sandy Silt	"	1.8%	28	"	Stable
155	39°-31'	104°-47'	Silty Clay PI>6	"	2.3%	20	"	Stable

FIELD OBSERVATIONS

DATA INDEX NO.	[3] LAT.	[4] LONG.	SOIL CLASS.	SOIL I.D. METHOD	CHANNEL BED SLOPE	DISCHARGE CFS	DISCHARGE EST. METH.	EROSION CONDITION [11]
156	39° 30'	104° 47'	Silty Clay	Field Est.	2.0%	20	Culvert	stable
157	39° 31'	104° 45'	Silty Clay PI>6	"	5.0%	50	"	eroded
158	39° 33'	104° 45'	Silty Clay PI>6	"	3.6%	18	"	stable
159	39° 33'	104° 45'	Silty Clay PI>6	"	2.1%	30	"	stable
160	39° 36'	104° 48'	Silty Clay PI>6	"	1.7%	20	"	stable
161	39° 36'	104° 45'	Silty Clay PI>6	"	5.8%	1.8	Slope-Area	stable
162	"	"	"	"	7.6%	1.8	"	eroded
163	"	"	"	"	4.6%	1.8	"	deposit
164	39° 36'	104° 45'	Soft sandstone	"	8.7%	1.8	"	eroded
165	39° 41'	104° 40'	Silty Clay PI>6	"	4.3%	165	Culvert	eroded
166	39° 40'	104° 40'	Silty Clay PI>6	"	3.0%	15	"	stable
167	39°-39'	104° 40'	Silt Clay	"	5.5%	10	"	stable
168	39°-39'	104° 40'	Silty Clay PI>6	"	8.7%	2	"	scoured
169	39°-37'	104° 40'	Silty Clay PI>6	"	5.0%	18	"	scoured
170	39° 37'	104° 40'	"	"	3.6%	18	"	stable
171	39° 33'	104° 42'	Silty Clay PI>6	"	2.1%	3	"	stable
172	39° 32'	104° 42'	Silty Clay	"	1.9%	44	"	stable
173	40°-	105° 22'	Gravelly Silt	"	12.5%	2	"	scoured
174	40°-	105° 22'	Gravel-Silt	"	9.1%	2	"	stable
175	40°-	105° 23'	"	"	60.0%	6	"	scoured
176	40°-	105° 23'	"	"	7.1%	1.3	Slope Area	eroded
177	"	"	"	"	2.2%	1.3	"	stable
178	40°-	105° 24'	"	"	13.2%	0.5	Slope Area	scoured
179	"	"	"	"	43.0%	0.5	"	"
180	"	"	"	"	9.6%	0.5	"	stable
181	"	"	"	"	42.0%	4	"	scoured
182	"	"	"	"	13.0%	4	Slope Area	stable
183	"	"	"	"	30.0%	1.2	"	scoured
184	"	"	"	"	10.0%	1.2	"	stable
185	39° 59'	105° 26'	Gravel Silt	"	5.1%	3	Culvert	stable
186	39° 58'	105° 26'	"	"	7.5%	1.1	Slope Area	scoured

FIELD OBSERVATIONS

DATA INDEX NO	3 LAT.	4 LONG.	SOIL CLASS.	SOIL I.D. METHOD	CHANNEL BED SLOPE	8 DISCHARGE Cfs	DISCHARGE EST. METH.	10 EROSION CONDITION
187	39°-58'	105°-26'	Gravel-Silt	Field Est.	7.3%	1.1	Slope Area	Stable
188	39°-56'	105°30'	"	"	5.0%	2.6	Culvert	Stable
190	39°-30'	104°45'	Silty Clay PI>6	"	7.7%	16	"	Scoured
191	39°-29'	104°45'	"	"	3.3%	130	"	"
192	39°-28'	104°43'	-	"	2.7%	52	"	Stable
193	"	"	Silty Sand	"	2.7%	52	"	"
194	39°28'	104°43'	Silty Clay PI>6	"	3.1%	50	"	"
195	"	"	Silty Sand	"	3.1%	50	"	"
196	"	"	Silty Clay PI>6	"	3.9%	6	"	Stable
197	"	"	"	"	8.9%	3	"	eroded
198	"	"	Sandy Silt	"	4.0%	3	"	Stable
199	"	"	Silty Clay PI>6	"	2.4%	25	"	Stable
200	"	"	"	"	35.0%	2.5	"	eroded
201	"	"	"	"	3.8%	20	"	Stable
202	"	"	"	"	3.8%	10	"	"
203	"	"	Silty Sand	"	1.5%	16	"	Stable
204	"	"	Silty Clay PI>6	"	1.4%	40	"	Stable
205	39°-28'	104°-44'	"	"	2.9%	16	"	Stable
206	"	"	Silty gravel	"	2.5%	2	"	"
207	"	"	Silty Clay PI>6	"	11.7%	1.5	Culvert	eroded
208	"	"	"	"	5.8%	2.5	"	Stable
209	"	"	"	"	8.8%	0.6	Slope-Area	Scoured
210	"	"	"	"	2.5%	0.6	"	Stable (deposit)
211	"	"	Soft Sandstone	"	8.8%	0.6	"	Stable
212	40°—	105°22'	Gravel Silt	"	20.0%	3.0	Culvert	beginning Scour
213	40°-	105°18'	"	"	4.7%	3	"	Stable
214	40°-	105°18'	"	"	12.0%	2	"	Scoured
215	"	"	"	"	7.6%	2	"	Stable
216	40°-	105°17'	"	"	8.9%	5	"	Stable
217	40°-3'	105°18'	Sandy-Silt	"	10.5%	1.5	"	SCOURED
218	40°-3'	105°18'	"	"	4.9%	1.5	"	Stable

LABORATORY DATA

The following data was taken from the report:

"Erosion Control Criteria for Drainage Channels"
by McWhorter, Carpenter and Clark
Mississippi State University
State College, Mississippi 39762
March 1968

Symbols and Notations:

S - Channel slope
TS - Test soil number
Q - Discharge, cfs
d - Mean depth, ft.
V - Mean velocity, fps
R - Hydraulic radius
n - Mannings n
E_c - Average accumulative erosion, 20 ft. reach
E_t - Average accumulative erosion, test section
F_o - Observed failure; ϕ = slight erosion, $\phi\phi$ = heavy erosion
F - * = Complete channel failure

Test Soil Numbers:

1	Clay-Sand	(SC)	PI>10
2	Gravel-Sand	(GW)	-
3	Silty-Sand	(SM)	PI>10
4	Fine-Sand	(SP)	PI< 6
5	Silt-Sand	(ML)	PI< 6
6	Clay	(CH)	PI>10
7	Clay-Silt	(CL)	PI>10
8	Clay-Silt	(CL)	PI>10
9	Silt-Clay	(ML)	PI= 6
10	Clay	(CH)	PI>10
11	Clay	(CL)	PI>10

Summary of test data.

S	TS	Q	d	V	R	n	VR	E_c	E_t	F_c	F
					Bare Soil Treatment						
.001	4	0.67	.264	1.27	.215	.013	0.273		-.006		
		1.02	.312	1.63	.228	.011	0.372		-.006		
		1.53	.547	1.40	.430	.019	0.602		.000		
		2.03	.544	1.87	.365	.013	0.681		.025		
		2.49	.737	1.69	.528	.018	0.892		.035		*
.001	6	1.06	.313	1.69	.224	.010	0.379		.014		
		2.05	.454	2.26	.255	.008	0.576		.021		
.010	6	0.78	.196	1.99	.183	.024	0.365		.055		*
		1.06	.241	2.20	.223	.025	0.490		.100		*
.010	6	0.28	.093	1.51	.089	.020	0.134		.039		*
		0.53	.125	2.12	.116	.017	0.246		.048		*
		0.79	.201	1.97	.188	.025	0.370		.061		*
		1.10	.246	2.24	.227	.025	0.508		.073		*
		1.46	.303	2.41	.277	.026	0.667		.128		*
.010	6	0.56	.146	1.92	.137	.021	0.263		.040		*
		0.90	.203	2.22	.188	.022	0.416		.064		*
.010	8	0.53	.131	2.02	.122	.018	0.248		.000		
		1.03	.220	2.34	.202	.022	0.473		.044		*
		1.53	.266	2.88	.236	.020	0.679		.094		*
		1.97	.310	3.18	.270	.020	0.857		.118		*
.010	8	0.55	.162	1.70	.154	.025	0.261		.003		
		1.02	.231	2.21	.214	.024	0.472		.050		*
		1.51	.329	2.29	.303	.029	0.695		.094		*
.010	8	0.53	.135	1.96	.126	.019	0.248		.044		*
		1.02	.180	2.83	.160	.015	0.454		.073		*
		1.53	.239	3.20	.208	.016	0.664		.087		*
.025	6	0.22	.056	1.96	.054	.017	0.107		.042		*
		0.46	.092	2.50	.088	.019	0.220		.039		*
		0.80	.181	2.21	.174	.033	0.385		.077		*
.025	6	0.09	.033	1.36	.032	.018	0.044		.008		
		0.21	.057	1.84	.055	.019	0.102		.021		
		0.54	.103	2.62	.098	.019	0.257		.057		*
.025	6	0.20	.059	1.69	.057	.021	0.097		.049		*
.025	10	0.51	.104	2.45	.099	.021	0.244		.027		
		1.07	.156	3.43	.145	.019	0.496		.037		

Summary of test data.

S	TS	Q	d	V	R	n	VR	E_c	E_t	F_o	F
					Bare Soil Treatment						
.025	2	0.12	.048	1.25	.047	.025	0.059	.002	-.007		
		0.43	.123	1.75	.120	.033	0.209	.023	.013	ø	
		0.62	.157	1.97	.152	.034	0.300	.078	.080	øø	*
		0.75	.173	2.17	.167	.033	0.361	.104	.137		*
.025	9	0.10	.037	1.35	.036	.019	0.049	.015	.040	øø	
		0.25	.075	1.67	.073	.025	0.122	.034	.082		*
.025	4	0.12	.052	1.15	.051	.028	0.059	.011	.028		
		0.24	.074	1.62	.072	.025	0.117	.015	.048	øø	*
		0.31	.083	1.87	.081	.023	0.150	.015	.070		*
		0.44	.098	2.24	.094	.022	0.211	.020	.087		*
		0.56	.121	2.31	.116	.024	0.269	.030	.107		*
.010	5	0.10	.062	0.81	.061	.029	0.049	-.009	-.020		
		0.24	.085	1.41	.082	.020	0.115	-.016	-.016		
		0.37	.113	1.64	.108	.021	0.176	-.008	-.013		
		0.44	.130	1.69	.123	.022	0.209	.012	.000		
		0.55	.155	1.77	.147	.023	0.260	.023	.023		
		0.64	.171	1.87	.161	.023	0.301	.037	.045		
		0.68	.183	1.86	.172	.025	0.320	.055	.060	ø	*
		0.83	.208	2.00	.195	.025	0.388	.056	.066	ø	*
		0.98	.249	1.97	.233	.029	0.459	.106	.091	ø	*
		1.03	.234	2.20	.216	.024	0.476	.111	.098	øø	*
		1.29	.273	2.36	.250	.025	0.591	.117	.111		*
		1.40	.305	2.30	.281	.028	0.644	.128	.133		*
.010	4	0.11	.053	1.04	.052	.020	0.054	-.012	.031	ø	
		0.24	.080	1.50	.077	.018	0.115	-.012	.045	ø	
		0.33	.096	1.72	.091	.017	0.156	-.077	.101	øø	*
		0.45	.114	1.97	.107	.017	0.211	.020	.097		*
		0.56	.144	1.94	.135	.020	0.263	.033	.106		*
		0.63	.159	1.98	.149	.021	0.295	.040	.133		*
		0.71	.165	2.15	.153	.020	0.329	.049	.151		*
		0.80	.187	2.14	.174	.022	0.371	.058	.138		*
		0.91	.207	2.20	.192	.022	0.421	.069	.173		*
		1.02	.229	2.23	.212	.024	0.471	.083	.175		*
.010	2	0.11	.048	1.15	.047	.017	0.053	-.007	.027		
		0.44	.112	1.96	.105	.017	0.206	.016	.000		
		0.51	.131	1.95	.123	.019	0.239	.031	.009		
		0.62	.155	2.00	.145	.021	0.290	.038	.006		
		0.66	.164	2.01	.153	.021	0.308	.036	.009		
		0.81	.164	2.47	.149	.017	0.369	.056	.037		
		0.91	.188	2.42	.172	.019	0.416	.068	.049	ø	
		1.00	.195	2.56	.177	.018	0.453	.076	.047	ø	
		1.20	.214	2.80	.191	.018	0.535	.112	.071	øø	*
		1.43	.261	2.74	.234	.021	0.641	.147	.113		*
		1.63	.297	2.74	.266	.022	0.730	.196	.178		*

Summary of test data.

S	TS	Q	d	V	R	n	VR	E_c	E_t	F_c	F
					Bare Soil Treatment						
.025	1	0.15	.049	1.53	.048	.020	0.073	.002	.009	ø	
		0.21	.079	1.33	.078	.032	0.103	.011	.012	øø	
		0.37	.099	1.87	.096	.026	0.180	.023	.025		*
		0.43	.125	1.72	.122	.034	0.209	.036	.034		*
		0.55	.150	1.83	.146	.035	0.267	.071	.081		*
		0.65	.167	1.95	.162	.036	0.315	.096	.108		*
		0.68	.171	1.99	.165	.036	0.329	.100	.126		*
.025	6	0.13	.051	1.27	.050	.025	0.064	.014	.017		
		0.25	.065	1.92	.063	.019	0.121	.080	.042	øø	*
.010	6	0.12	.061	0.98	.060	.023	0.059	-.006	-.009	ø	
		0.24	.091	1.32	.088	.022	0.116	-.019	-.016	ø	
		0.36	.103	1.75	.098	.018	0.170	-.006	-.009	ø	
		0.46	.134	1.72	.127	.022	0.218	.010	.026	ø	
		0.53	.150	1.77	.142	.023	0.251	.028	.034	ø	*
		0.65	.172	1.89	.162	.023	0.306	.037	.058	ø	*
		0.72	.188	1.91	.177	.024	0.338	.045	.085	øø	*
		0.82	.208	1.97	.195	.025	0.384	.049	.103		*
.010	9	0.12	.064	0.94	.063	.025	0.059	-.003	.009	ø	
		0.23	.094	1.22	.091	.025	0.111	-.002	.009	ø	
		0.32	.102	1.57	.097	.020	0.153	-.003	.006	ø	
		0.27	.118	1.14	.115	.031	0.131	.003	.031	ø	
		0.55	.133	2.07	.124	.018	0.256	.015	.044	øø	*
		0.66	.163	2.02	.152	.021	0.308	.019	.049		*
		0.71	.175	2.03	.163	.022	0.331	.025	.071		*
		0.88	.215	2.05	.201	.025	0.410	.051	.100		*
		1.00	.222	2.25	.205	.023	0.461	.037	.077		*
.025	7	0.11	.039	1.41	.038	.019	0.054	.000	.016		
		0.22	.057	1.93	.055	.018	0.107	.019	.030		*
		0.33	.077	2.14	.074	.019	0.159	.031	.053	øø	*
		0.46	.101	2.28	.097	.022	0.221	.049	.087		*
		0.56	.111	2.52	.106	.021	0.267	.058	.113		*
.010	1	0.11	.073	0.75	.072	.034	0.054	.006	.001		
		0.22	.091	1.21	.088	.024	0.107	-.026	-.007		
		0.34	.099	1.72	.094	.018	0.161	-.030	-.007		
		0.44	.134	1.64	.128	.023	0.209	-.015	-.005	ø	
		0.55	.132	2.08	.123	.018	0.256	-.009	.014	ø	
		0.67	.158	2.12	.147	.020	0.311	-.024	.011	øø	
		0.75	.174	2.16	.161	.020	0.348	-.010	.025		*
		0.83	.192	2.16	.178	.022	0.385	-.002	.028		*
		0.91	.201	2.26	.185	.021	0.419	.003	.028		*
		1.01	.220	2.30	.202	.022	0.465	.012	.062		*
		1.14	.248	2.30	.228	.024	0.524	.036	.079		*
		1.35	.268	2.52	.243	.023	0.613	.028	.089		*

Summary of test data.

S	TS	Q	d	V	R	n	VR	E_c	E_t	F_o	F
					Bare Soil Treatment						
.025	10	0.44	.099	2.22	.095	.022	0.212		.031		
		0.98	.144	3.40	.134	.018	0.454		.040		
.050	2	0.14	.041	1.71	.040	.023	0.069		.013		
		0.26	.056	2.32	.055	.021	0.127		.001		
		0.49	.095	2.58	.092	.026	0.238		.252		*
.025	11	0.12	.049	1.22	.048	.025	0.059	.017			
		0.21	.070	1.50	.069	.026	0.103	.029			
		0.29	.089	1.63	.087	.028	0.142	.039			
		0.43	.109	1.97	.106	.027	0.208	.053		Ø	
		0.45	.110	2.05	.106	.026	0.217	.065		Ø	*
		0.67	.171	1.96	.166	.036	0.324	.034		ØØ	*
.010	11	0.10	.077	0.65	.076	.041	0.049	-.006			
		0.16	.115	0.70	.113	.050	0.079	-.008			
		0.31	.140	1.11	.136	.036	0.151	.070			
		0.43	.154	1.40	.148	.030	0.207	.070			*
		0.49	.166	1.48	.159	.030	0.235	.072			*
		0.60	.193	1.55	.184	.031	0.287	.093			*
		0.67	.218	1.54	.208	.034	0.320	.115		Ø	*
		0.74	.227	1.63	.216	.033	0.352	.124		Ø	*
		0.90	.260	1.73	.246	.034	0.426	.138		Ø	*
		0.97	.276	1.76	.261	.035	0.459	.156		Ø	*
		1.15	.307	1.87	.289	.035	0.541	.146		Ø	*
		1.19	.335	1.78	.317	.039	0.563	.157		ØØ	*
.010	3	0.11	.053	1.04	.052	.020	0.054	-.006	-.020		
		0.23	.072	1.60	.069	.016	0.110	.002	.003		
		0.29	.080	1.81	.076	.015	0.137	.018	.019	Ø	
		0.42	.110	1.91	.103	.017	0.197	.034	.060	Ø	
		0.53	.135	1.96	.126	.019	0.248	.064	.099	Ø	
		0.59	.167	1.77	.158	.025	0.279	.079	.104	Ø	*
		0.72	.179	2.01	.167	.022	0.336	.068	.070	Ø	*
		0.83	.199	2.09	.185	.023	0.386	.059	.085	Ø	*
		0.94	.203	2.32	.187	.021	0.432	.073	.094	Ø	*
		0.99	.221	2.24	.204	.023	0.457	.077	.097	Ø	*
		1.18	.237	2.49	.216	.021	0.537	.078	.087	Ø	*
		1.34	.250	2.68	.225	.021	0.603	.075	.119	Ø	*
		1.52	.268	2.84	.239	.020	0.677	.086	.132	ØØ	*
.010	8	0.11	.060	0.92	.059	.025	0.054	-.006	.002		
		0.21	.073	1.44	.070	.018	0.101	-.002	.008		
		0.34	.108	1.57	.103	.021	0.162	-.023	.004	Ø	
		0.46	.118	1.95	.111	.018	0.216	.003	.030	ØØ	*
		0.56	.120	2.33	.110	.015	0.257	.002	---		*

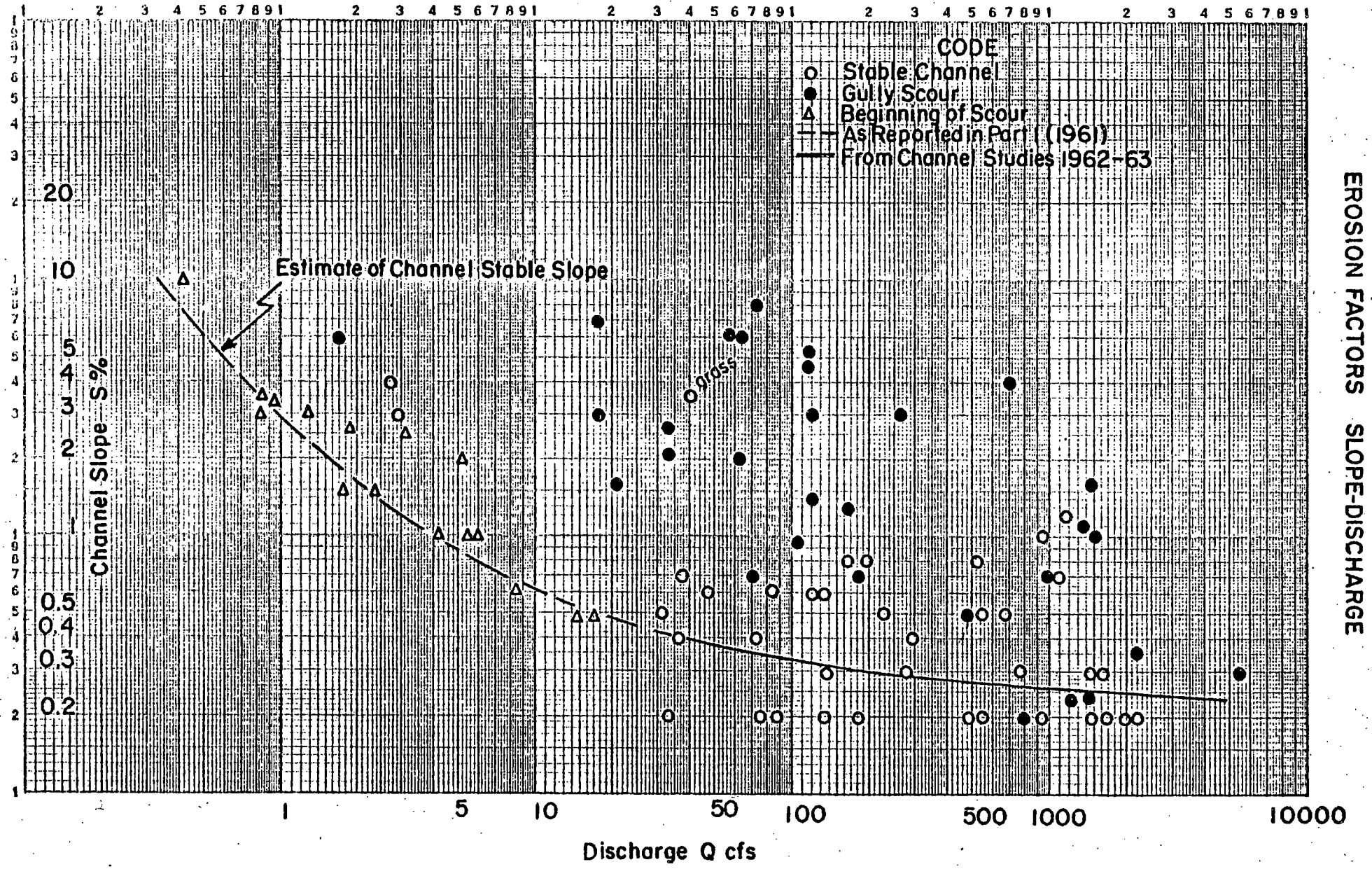
Summary of test data.

S	TS	Q	d	V	R	n	VR	E_c	E_t	F_o	F
					Bare Soil Treatment						
.010	7	0.12	.058	1.03	.057	.021	0.059	-.006	.099		
		0.24	.076	1.58	.073	.016	0.115	.000	.023		
		0.34	.095	1.79	.090	.017	0.161	.004	.035	Ø	
		0.44	.118	1.86	.111	.018	0.207	.011	.044	ØØ	*
		0.57	.145	1.97	.136	.020	0.267	.013	.071		*
		0.67	.162	2.07	.151	.020	0.312	.021	.077		*
		0.72	.177	2.03	.165	.022	0.336	.032	.083		*
		0.81	.193	2.10	.180	.023	0.377	.019	.096		*
		1.04	.219	2.37	.201	.021	0.476	.030	.061		*
		1.28	.237	2.70	.213	.020	0.575	.032	.086		*
		1.42	.236	3.01	.208	.017	0.625	.019	.080		*
		1.60	.255	3.14	.222	.017	0.698	.038	.089		*
.025	5	0.11	.039	1.41	.038	.019	0.054	.001	.002		
		0.25	.069	1.81	.067	.021	0.121	.039	.030	Ø	
		0.33	.093	1.77	.090	.027	0.160	.062	.071	ØØ	*
		0,49	.129	1.90	.125	.031	0.238	.098	.095		*
		0.58	.153	1.90	.148	.035	0.281	.117	.131		*
		0.62	.170	1.82	.165	.039	0.301	.123	.130		*
		0.67	.192	1.74	.187	.044	0.326	.201	.165		*
		0.80	.195	2.05	.188	.038	0.386	.220	.210		*
		0.95	.237	2.00	.229	.044	0.459	.193	.252		*
.025	3	0.10	.046	1.09	.045	.028	0.049	.006	.009	Ø	
		0.24	.073	1.64	.071	.025	0.117	.012	.020	Ø	
		0.34	.095	1.79	.092	.027	0.165	.028	.040	Ø	*
		0.44	.123	1.79	.120	.032	0.214	.047	.045	Ø	*
		0.54	.142	1.90	.138	.033	0.262	.068	.056	Ø	*
		0.62	.152	2.04	.147	.032	0.300	.075	.047	Ø	*

APPENDIX C- KEELEY SCATTER DIAGRAMS

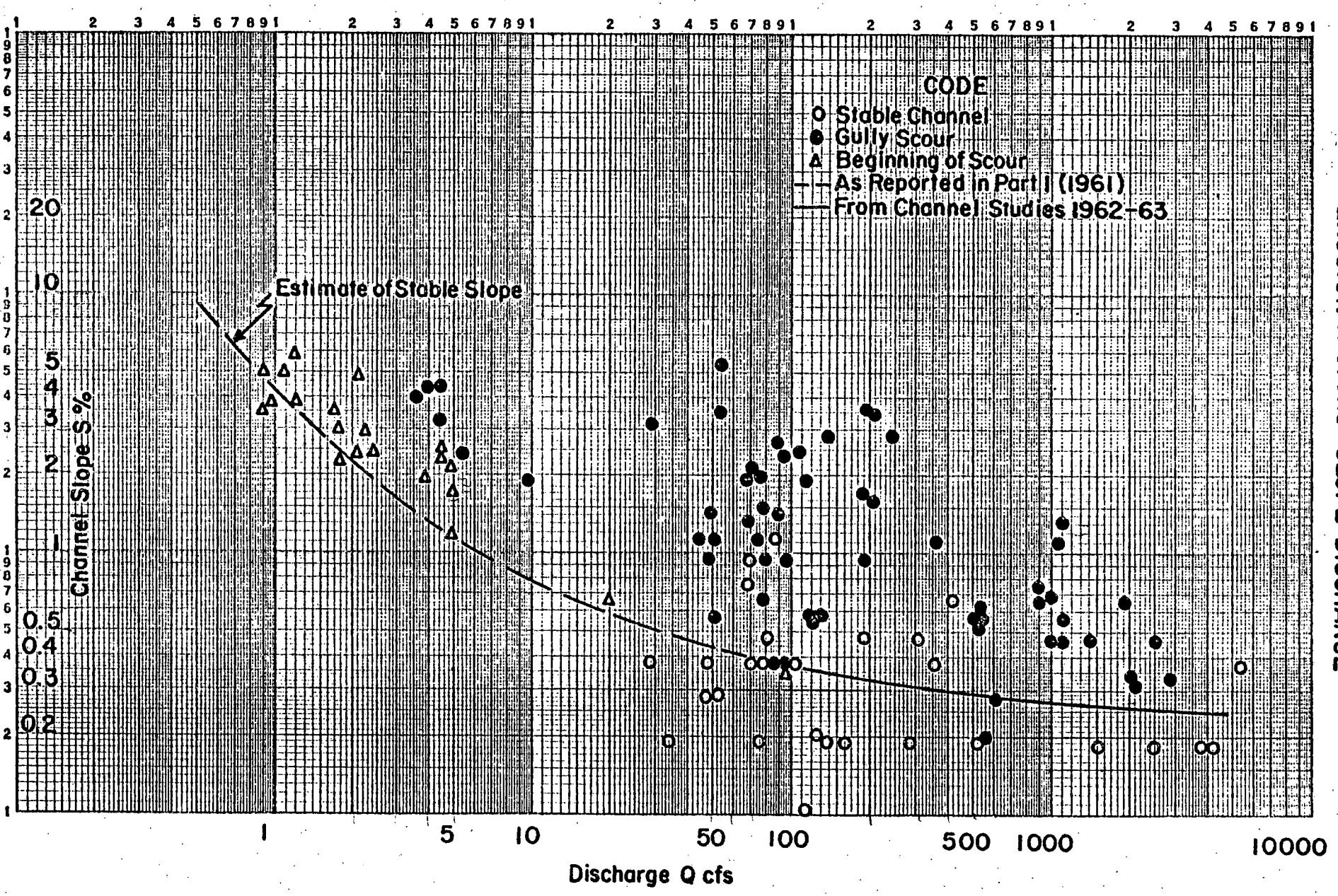
Copies of the scatter diagrams from Reference 5 are included in this Appendix. The data points on these diagrams made up about one half of the data points on Figures 4 through 11.

EROSION FACTORS SLOPE-DISCHARGE



SANDY SILTS
PI<6

Figure 3-43



EROSION FACTORS SLOPE-DISCHARGE

SILT CLAYS
PI 6-10

Figure 3-44

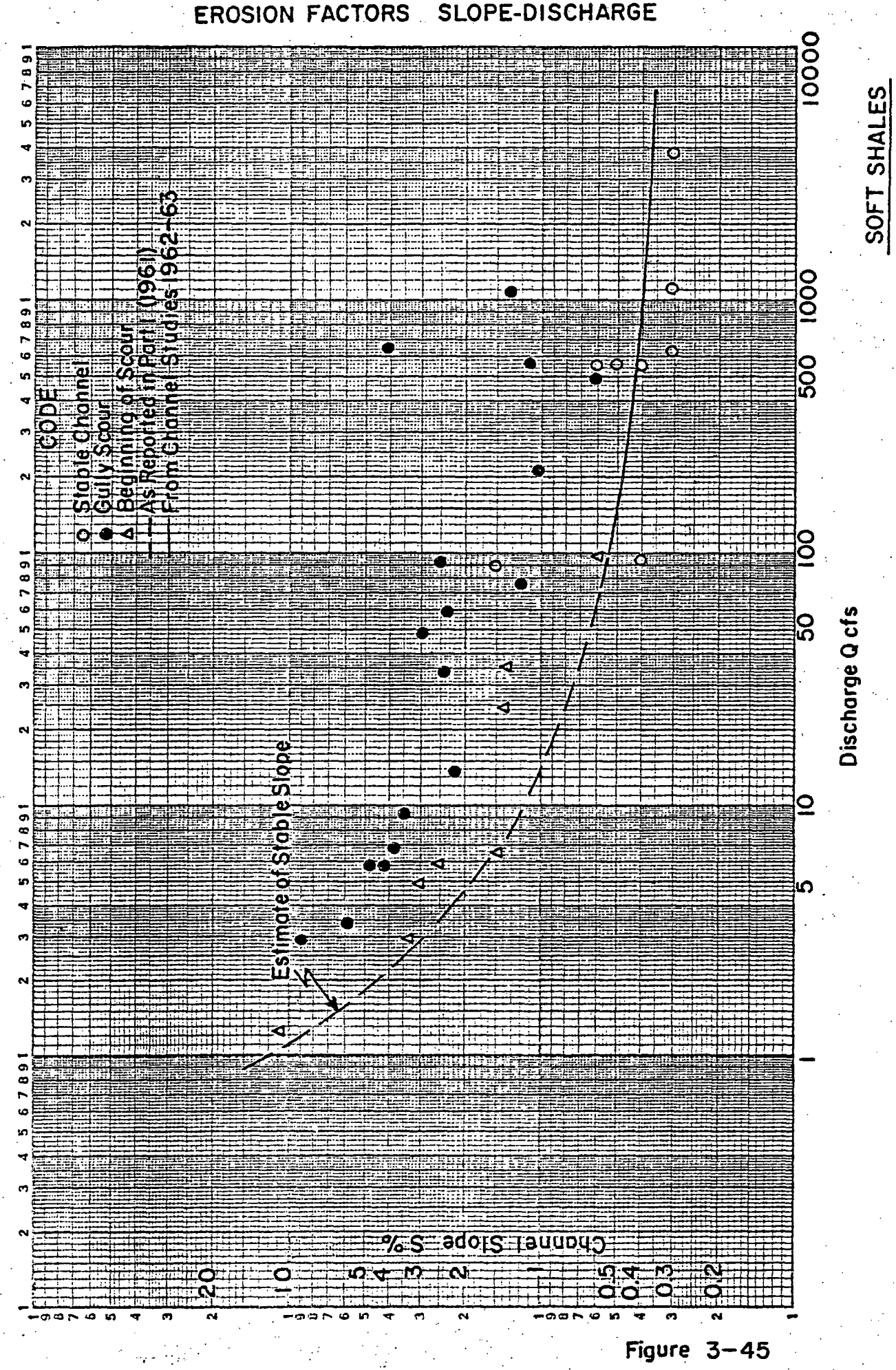

EROSION FACTORS SLOPE-DISCHARGE
SOFT SHALES
CODE
O Stable Channel
● Gully Scour
Δ Beginning of Scour
As Reported in Part I (1961)
From Channel Studies 1962-63
Estimate of Stable Slope
Channel Slope S %
Discharge Q cfs
20
10
5
4
3
2
1
0.5
0.4
0.3
0.2
1
10
50
100
500
1000
10000

Figure 3-45

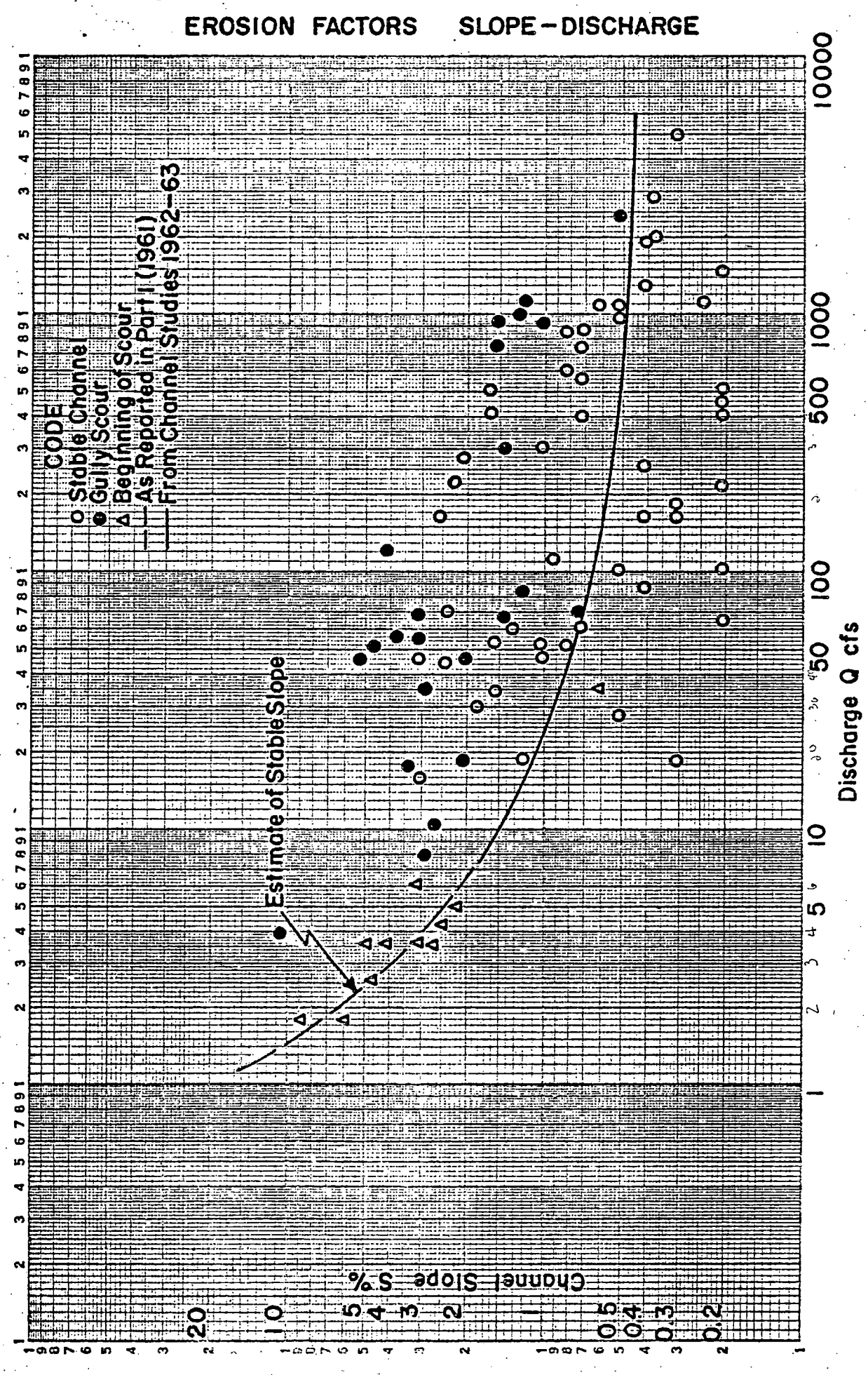
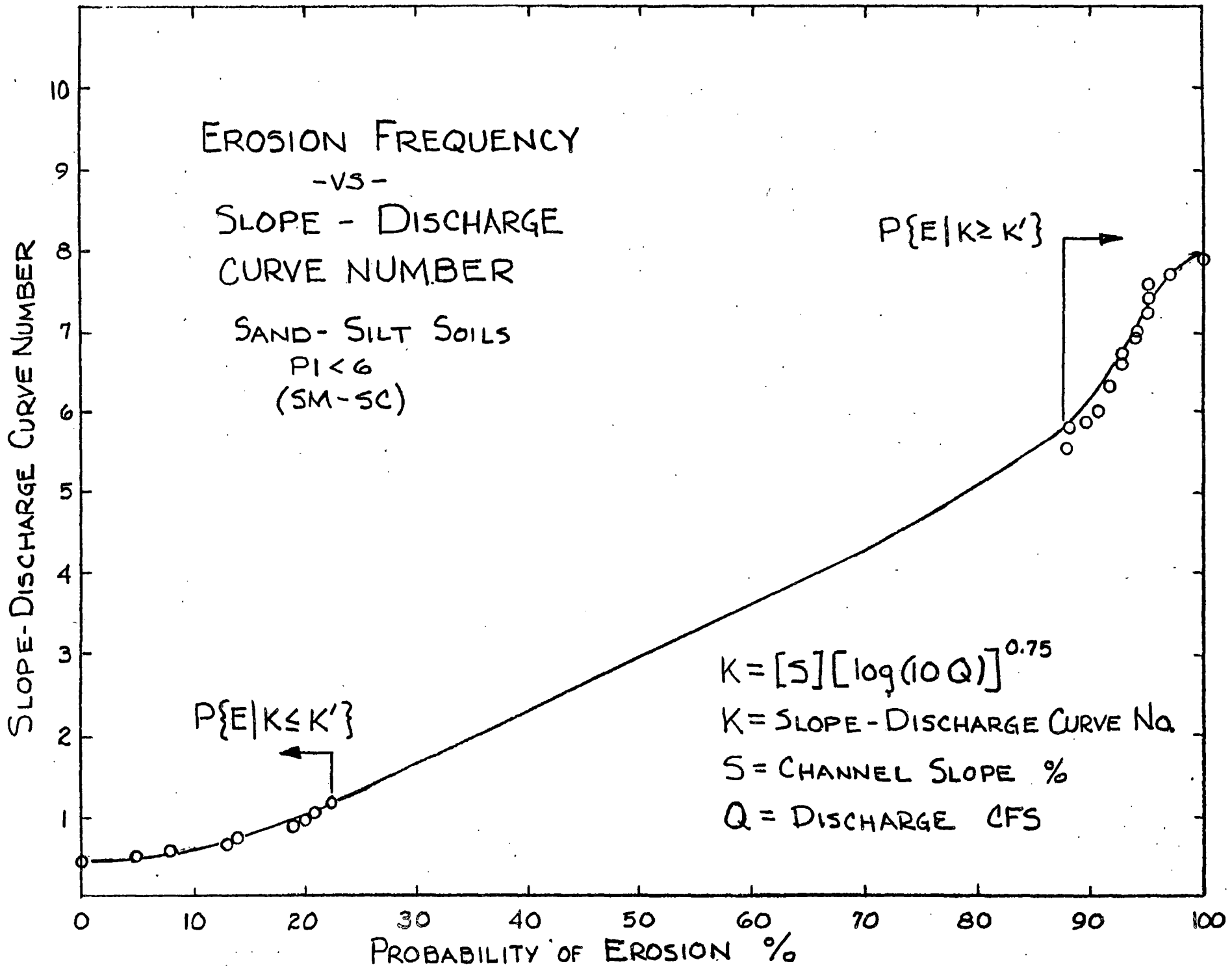
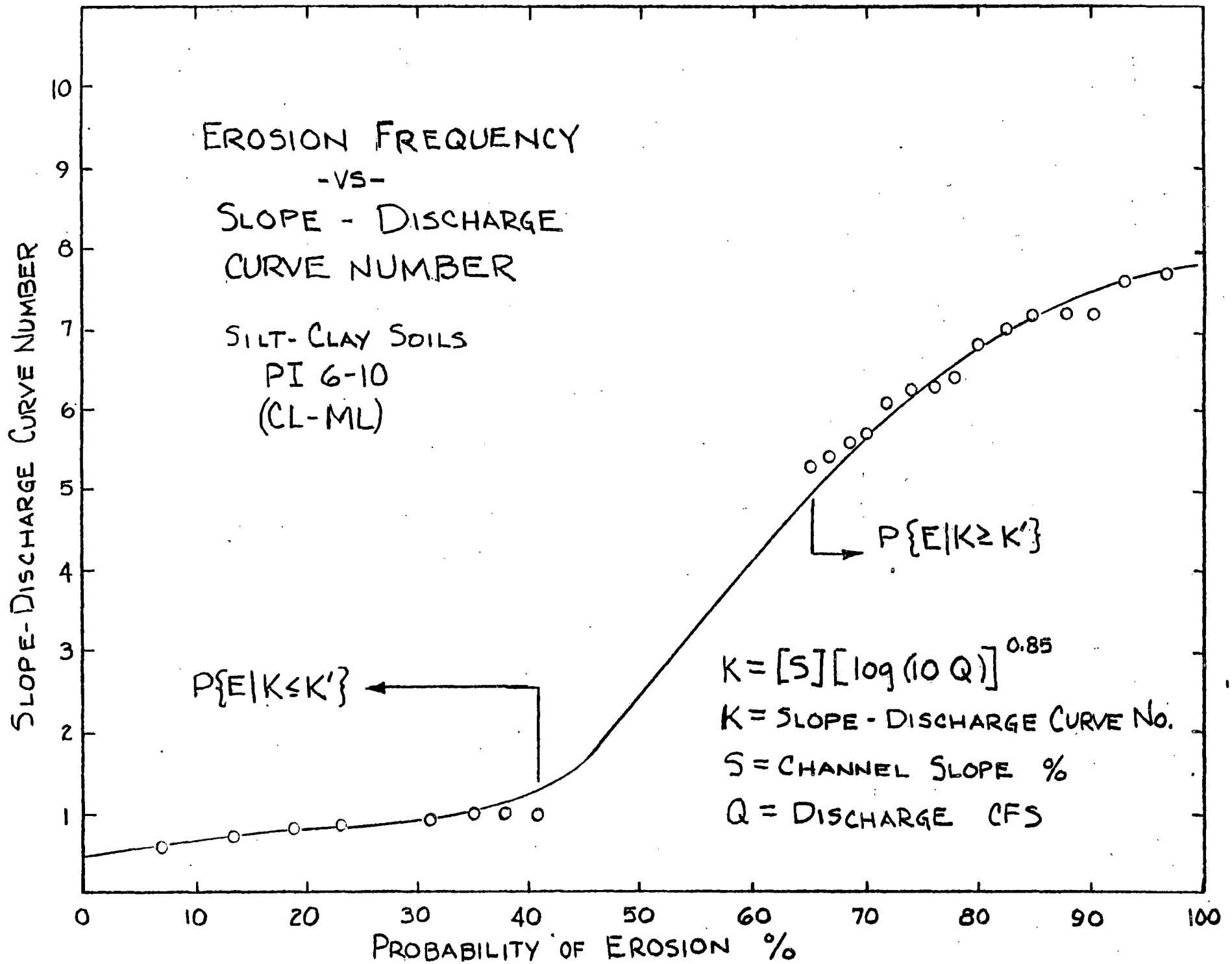

EROSION FACTORS SLOPE-DISCHARGE
CODE
Stable Channel
Gully Scour
Beginning of Scour
As Reported in Part I (1961)
From Channel Studies 1962-63
Estimate of Stable Slope
Channel Slope S %
Discharge Q cfs
CLAYS
PI>10

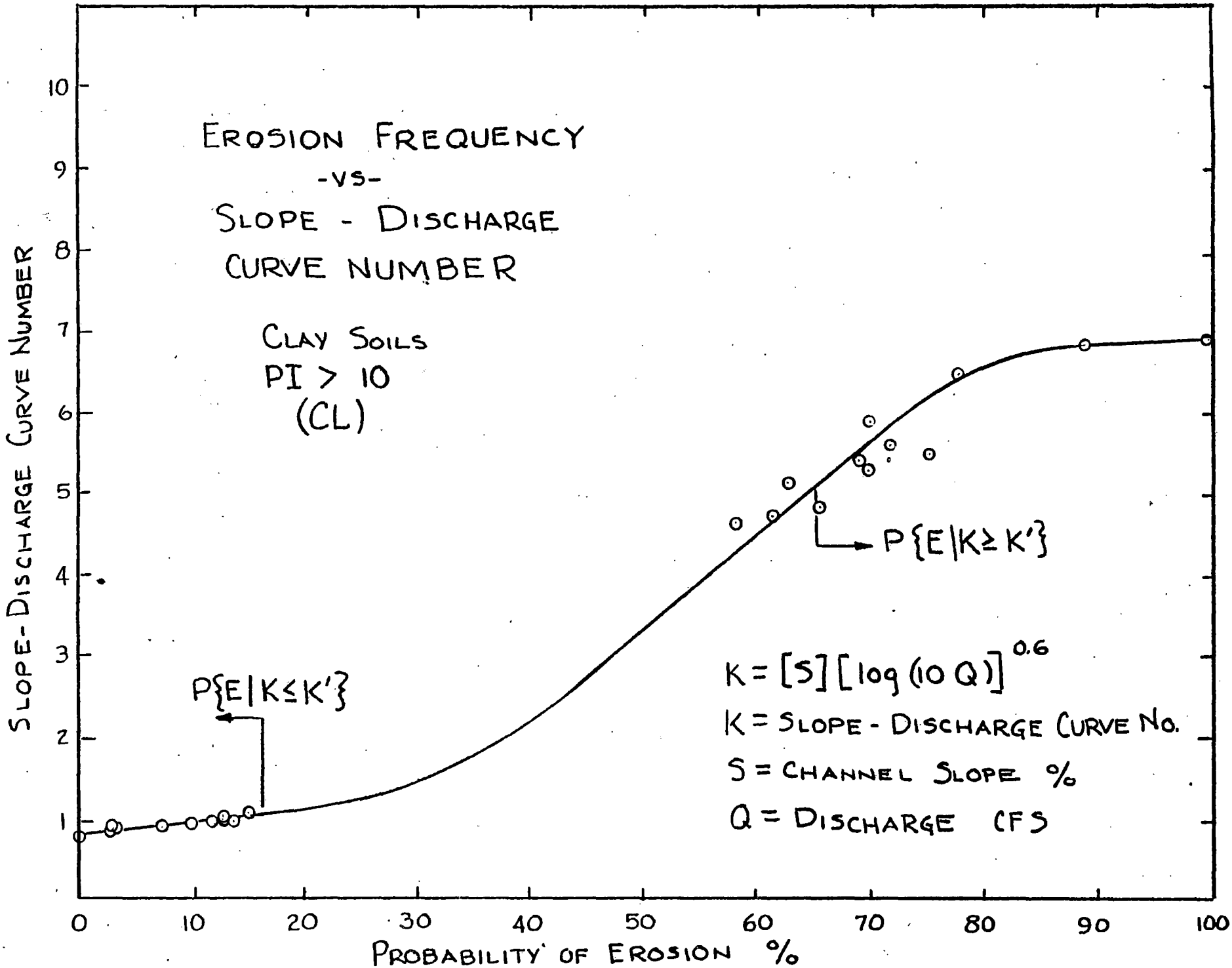
Figure 3-46

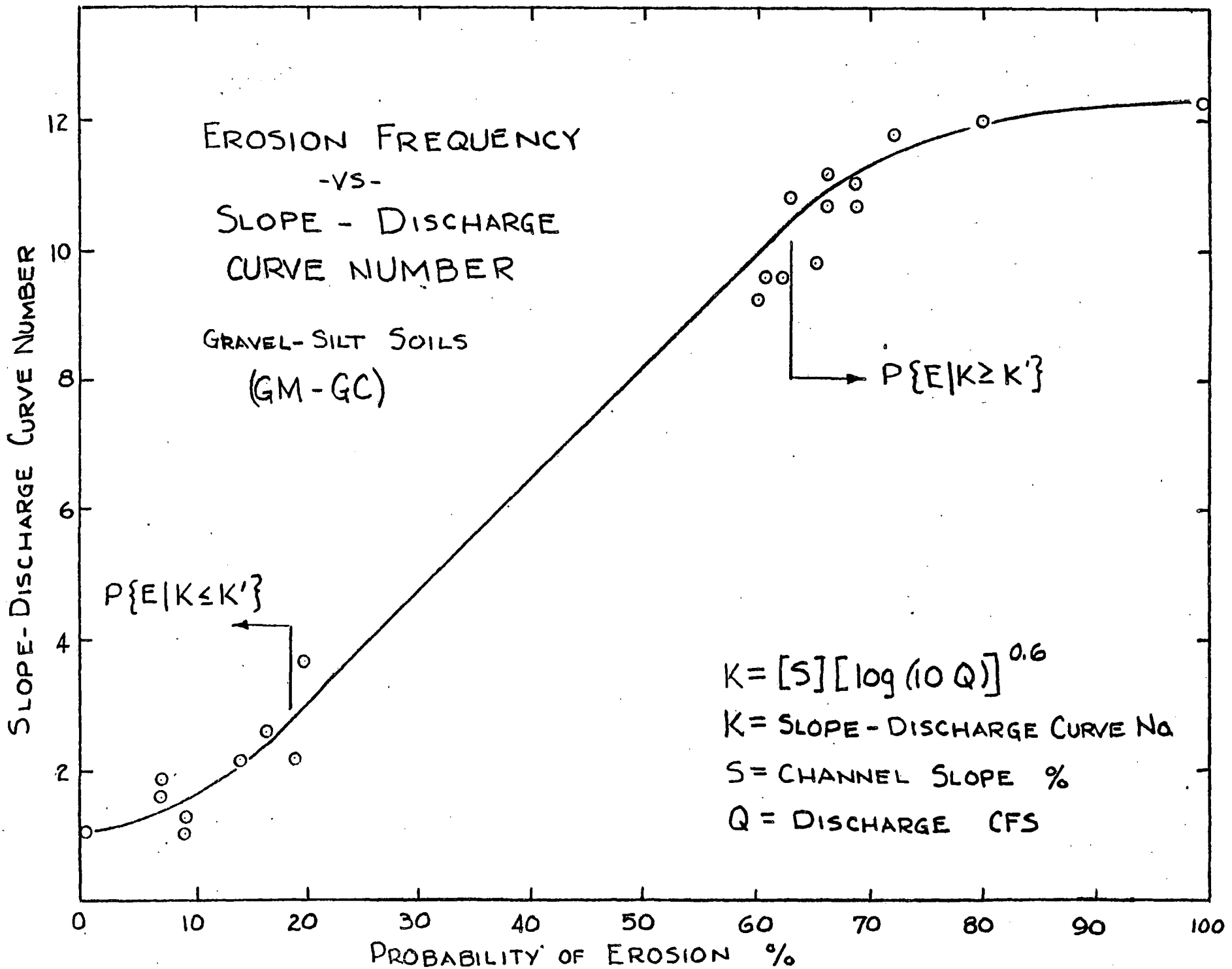
APPENDIX D - EROSION FREQUENCY CURVES

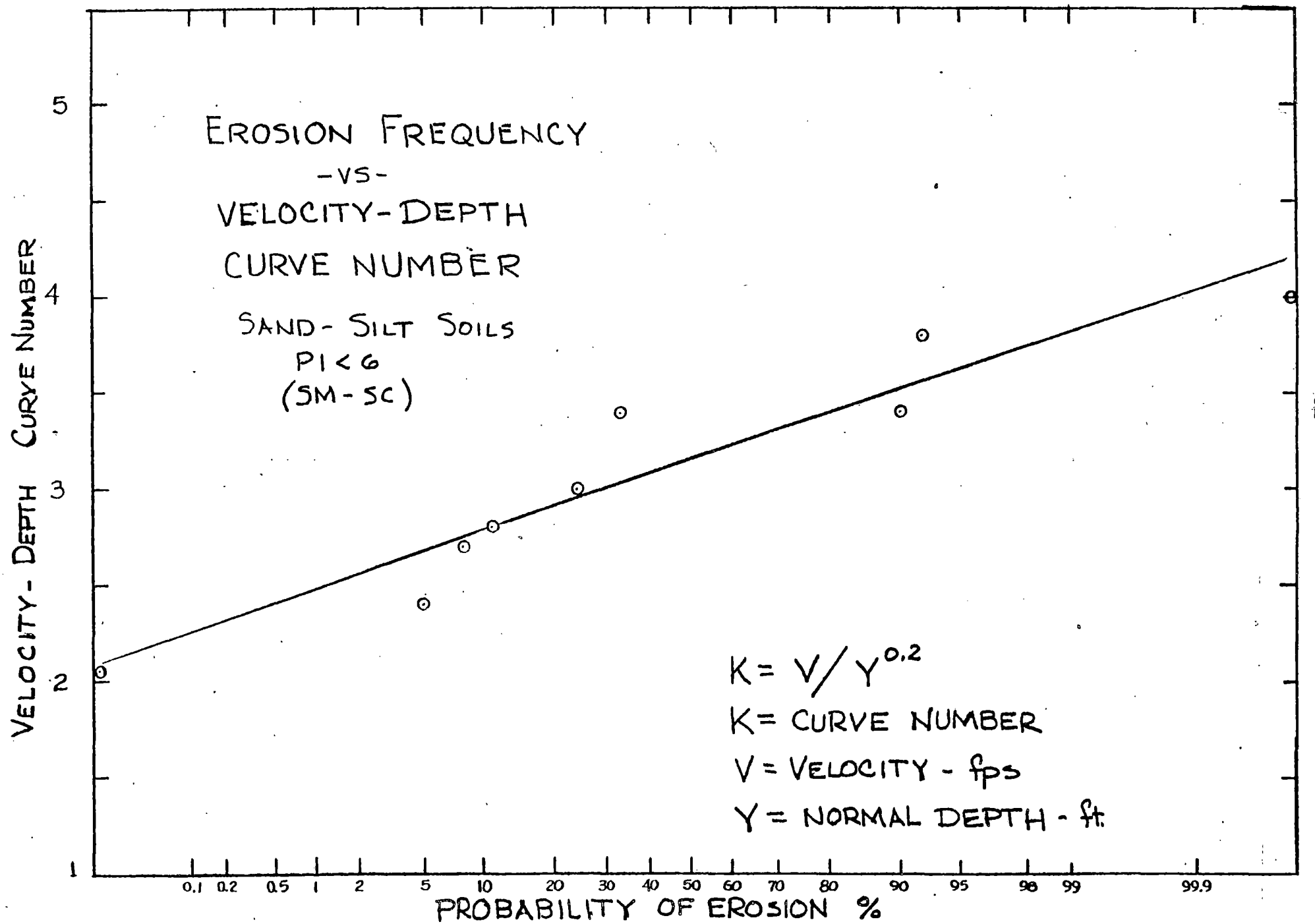
Erosion frequency curves were derived as shown in Figure 3 of this report for the following soil groups: sand-silt, silt-clay, clay and gravel-silt. The velocity-depth erosion frequency curves approximated a normal distribution and were assumed to be normally distributed. The discharge-slope erosion frequency curves were not normally distributed, and the curve which best fit the data points was used.

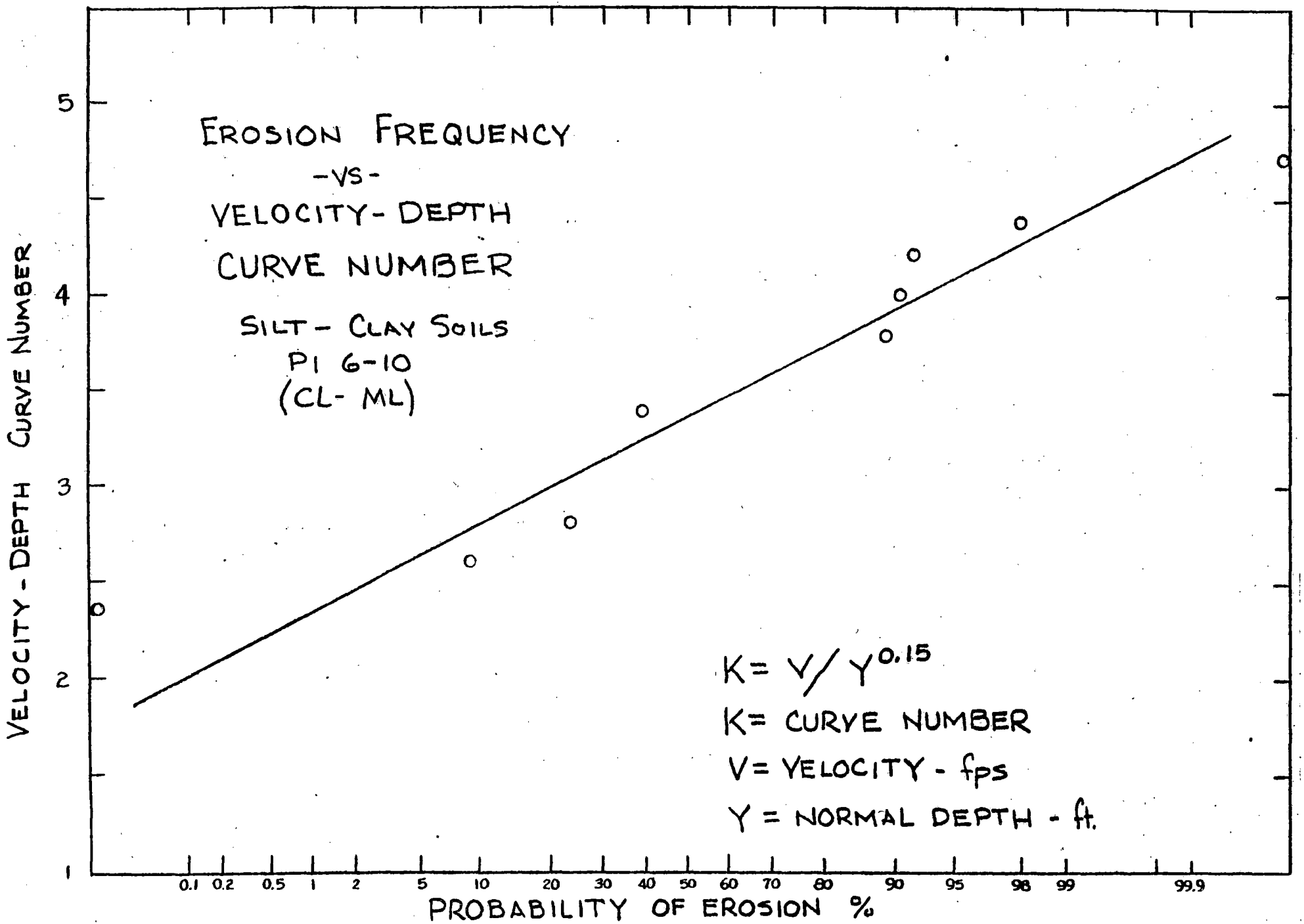

EROSION FREQUENCY
-VS-
SLOPE - DISCHARGE
CURVE NUMBER
SAND- SILT SOILS
PI < 6
(SM-SC)
P{E|K≥K'}
P{E|K≤K'}
K = [S][log(10 Q)]^0.75
K = SLOPE-DISCHARGE CURVE No.
S = CHANNEL SLOPE %
Q = DISCHARGE CFS
SLOPE-DISCHARGE CURVE NUMBER
PROBABILITY OF EROSION %
0
10
20
30
40
50
60
70
80
90
100
1
2
3
4
5
6
7
8
9
10

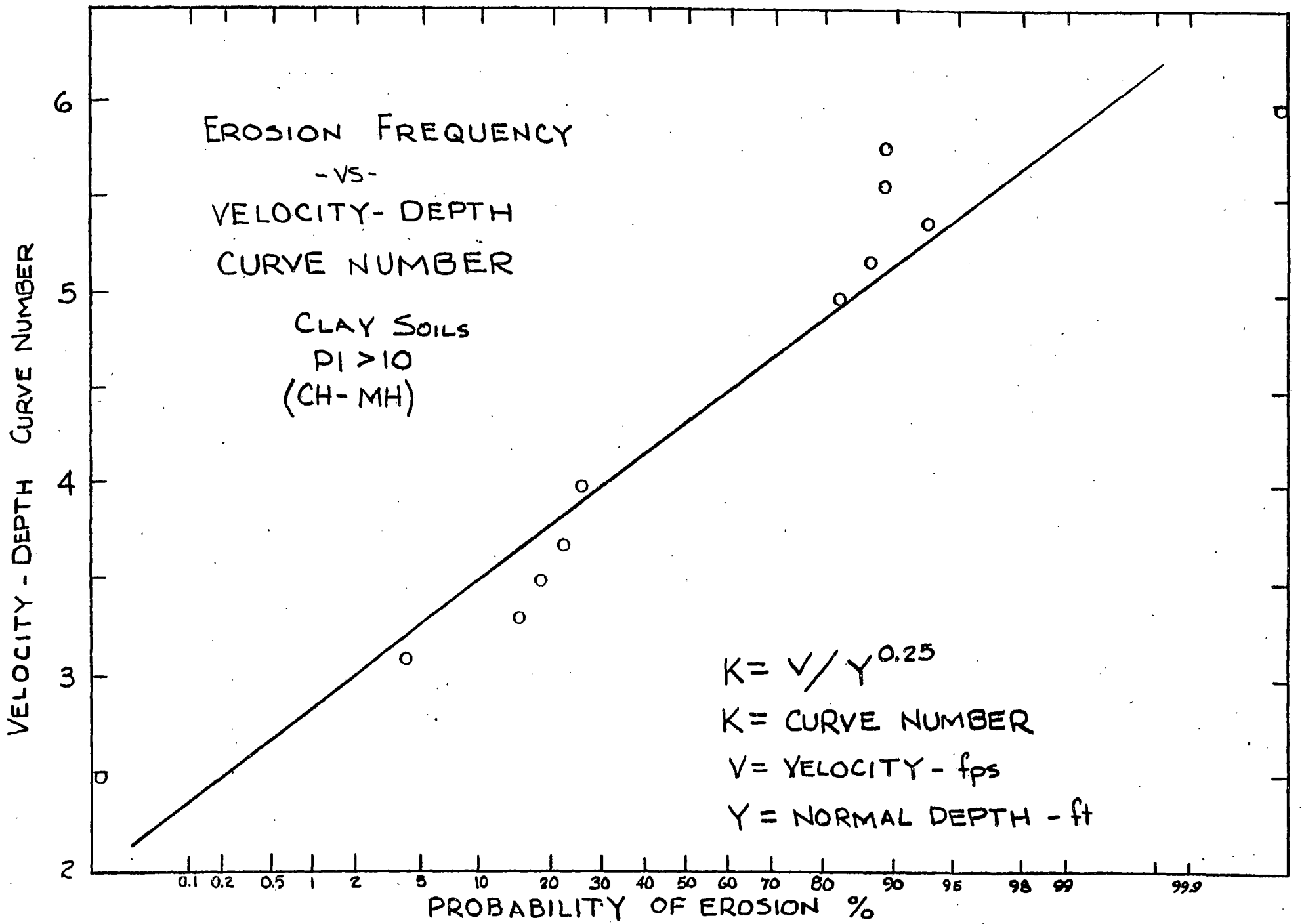

EROSION FREQUENCY
-VS-
SLOPE - DISCHARGE
CURVE NUMBER
SILT-CLAY SOILS
PI 6-10
(CL-ML)
SLOPE-DISCHARGE CURVE NUMBER
PROBABILITY OF EROSION %
P{E|K≤K'}
P{E|K≥K'}
K=[S][log(10 Q)]^0.85
K = SLOPE - DISCHARGE CURVE No.
S = CHANNEL SLOPE %
Q = DISCHARGE CFS
0
10
20
30
40
50
60
70
80
90
100
1
2
3
4
5
6
7
8
9
10

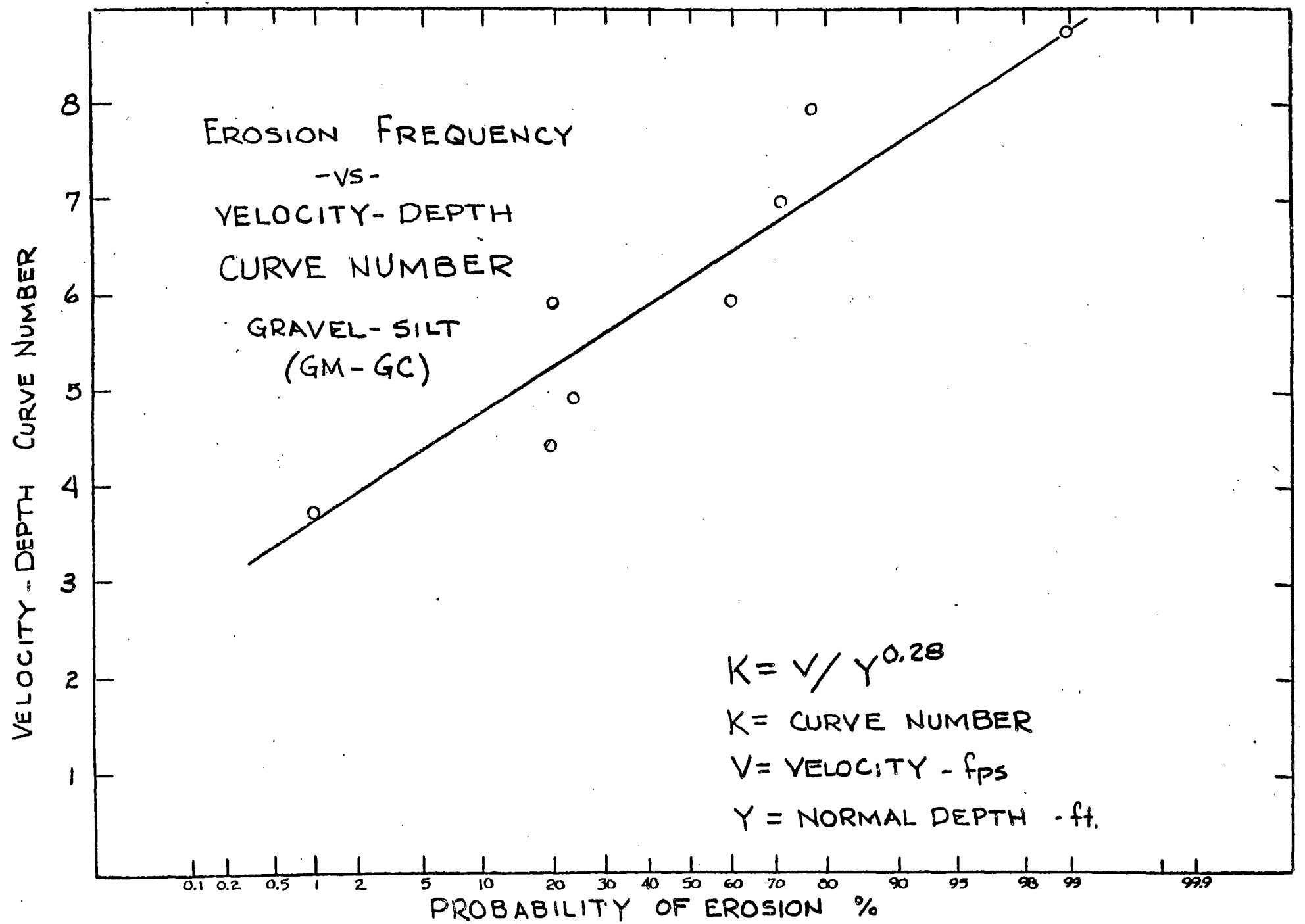

EROSION FREQUENCY
-VS-
SLOPE - DISCHARGE
CURVE NUMBER
CLAY SOILS
PI > 10
(CL)
SLOPE-DISCHARGE CURVE NUMBER
PROBABILITY OF EROSION %
P{E|K≤K'}
P{E|K≥K'}
K = [S][log (10 Q)]^0.6
K = SLOPE - DISCHARGE CURVE NO.
S = CHANNEL SLOPE %
Q = DISCHARGE CFS
0
10
20
30
40
50
60
70
80
90
100
1
2
3
4
5
6
7
8
9
10


EROSION FREQUENCY
-VS-
SLOPE - DISCHARGE
CURVE NUMBER
GRAVEL-SILT SOILS
(GM-GC)
P{E|K≥K'}
P{E|K≤K'}
K=[S][log(10 Q)]^0.6
K= SLOPE-DISCHARGE CURVE No
S= CHANNEL SLOPE %
Q= DISCHARGE CFS
SLOPE-DISCHARGE CURVE NUMBER
PROBABILITY OF EROSION %
0
10
20
30
40
50
60
70
80
90
100
2
4
6
8
10
12


EROSION FREQUENCY
-VS-
VELOCITY-DEPTH
CURVE NUMBER
SAND-SILT SOILS
PI < 6
(SM-SC)
VELOCITY-DEPTH CURVE NUMBER
1
2
3
4
5
0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.9
PROBABILITY OF EROSION %
K = V / Y^0.2
K = CURVE NUMBER
V = VELOCITY - fps
Y = NORMAL DEPTH - ft.


EROSION FREQUENCY
-VS-
VELOCITY-DEPTH
CURVE NUMBER
SILT - CLAY SOILS
PI 6-10
(CL- ML)
$K = V / Y^{0.15}$
K= CURVE NUMBER
V= VELOCITY - fps
Y = NORMAL DEPTH - ft.
VELOCITY - DEPTH CURVE NUMBER
1
2
3
4
5
0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.9
PROBABILITY OF EROSION %


EROSION FREQUENCY
-VS-
VELOCITY- DEPTH
CURVE NUMBER
CLAY SOILS
PI >10
(CH- MH)
K= V/ Y^0.25
K= CURVE NUMBER
V= VELOCITY - fps
Y = NORMAL DEPTH - ft
VELOCITY - DEPTH CURVE NUMBER
PROBABILITY OF EROSION %
2
3
4
5
6
0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.9


EROSION FREQUENCY
-VS-
VELOCITY- DEPTH
CURVE NUMBER
GRAVEL- SILT
(GM-GC)
VELOCITY - DEPTH CURVE NUMBER
1
2
3
4
5
6
7
8
0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.9
PROBABILITY OF EROSION %
K = V / Y^0.28
K = CURVE NUMBER
V = VELOCITY - fps
Y = NORMAL DEPTH - ft.